Interactive GIS Approach to Generate Capture Curves at the Massachusetts Military Reservation, Cape Cod, Massachusetts

by

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B.S. Hydrology
University of New Hampshire, 1997

Submitted to the Department of Civil and Environmental Engineering
In Partial Fulfillment of the Requirements for the Degree of

MASTER OF ENGINEERING
IN CIVIL AND ENVIRONMENTAL ENGINEERING

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
June 1998

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ABSTRACT

The Massachusetts Military Reservation Installation and Restoration Program (MMRIRP) regularly approves pump-and-treat systems to contain migrating plumes at the MMR. These systems are difficult to design because there are a number of plausible pumping scenarios that can be implemented at a site. Before the design engineer can begin to optimize a remediation solution, he/she must first quantify the capture potential of various pumping scenarios. Due to the infinite number of plausible pumping schemes, the task of quantifying the capture potential for each system is time-consuming, making it a perfect candidate for software automation.

The difficulty in quantifying the effectiveness of various pumping schemes is attributed to the lack of user-friendly applications that accurately represent the current conditions of a site. However, Geographical Information System (GIS) has the potential to alleviate these problems. GIS is a tool used to map, manage, and analyze geographic data. Environmental Systems Research Institute (ESRI) has developed GIS products that have the strength to perform complex analyses without compromising the degree of user-friendliness. With our growing dependence upon computers, the need for user-friendly software is rapidly escalating. Software applications that provide back-end analytical capabilities through a front-end, menu-driven graphical interface are more the rule than the exception.

Noting the MMR's trend in prescribing pump-and-treat systems, and the need for visual software packages that can aid in the design process of remediation systems, the "Capture-Curve Approximation" (CCA) program was created. This program employs ArcView GIS 3.0a to serve as the graphical interface between the user and the back-end analytical program that approximates the area contributing to an extraction well.

This program has the potential to facilitate pump-and-treat designs at the MMR. Although the results are only an approximation, they can be used to find pumping scenarios that promote the desired capture. This program also has the potential to increase public awareness and involvement at the MMR. It has the ability to be served over the web, thereby making it available to anyone interested in the MMR.

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Acknowledgments

I would like to take this opportunity to thank everyone who contributed to this thesis. First and foremost, I would like to thank my advisor, Dr. Peter Shanahan. Pete proved to be an invaluable thesis advisor, providing endless support and guidance. I would also like to thank Bruce Jacobs for all of his technical assistance. Between Pete and Bruce, any question or obstacle I ran into, whether it was related to ground-water theory or object-oriented programming, they had an answer.

I would also like to thank Phil Chernin and Cord Thomas at CDM for donating their time and ideas to this project. Phil originally came up with the overall concept of the CCA program and Cord provided essential technical support, particularly with the Avenue coding. Their assistance was instrumental to the success of the CCA program.

Last, and most importantly, I want to thank my family and friends. They all provided me with endless support, encouragement, and love. Mom and Dad, thank you for instilling in me the confidence, ambition, and courage to achieve all my goals. Eric, I want to thank you for all the lessons you've taught me. I've learned by your example and perseverance at West Point, that even the most insurmountable challenges can be overcome. Kevin, thank you for your immeasurable patience, commitment, and love. You all were my pillar of strength throughout this year and everything I am and have achieved is because of all of you.

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1. Introduction

1.1 Location

The Massachusetts Military Reservation (MMR) is located on the upper western part of Cape Cod, Massachusetts. It occupies 22,000 acres (35 square miles) within the towns of Bourne, Sandwich, Mashpee, and Falmouth in Barnstable County (Figure 1-1). The MMR consists of facilities operated by the U.S. Coast Guard, the Army National Guard, the U.S. Air Force, Air National Guard, Veterans Administration, and the Commonwealth of Massachusetts.

MMR is comprised of four principal functional areas (Jacobs, 1997c):

- Cantonment Area: This southern portion of the reservation is the most actively used section of the MMR. It occupies 5,000 acres and is the location of administration, operational, maintenance, housing, and support facilities for the base. The Otis Air Force Base facilities are located in the southeast portion of the Cantonment Area.
- Range Maneuver and Impact Area: This northern part of the MMR consists of 14,000 acres and is used for training and maneuvers.
- Massachusetts National Cemetery: This area occupies the western edge of the MMR and contains the Veterans Administration Cemetery and support facilities.
- Cape Cod Air Force Station (AFS): This 87-acre section is at the northern portion of the Range and Maneuver and Impact Area and is known as the Precision Acquisition Vehicle Entry - Phased Array Warning System.

A majority of the facilities at the MMR are located in the southern portion, while the northern portion consists of several firing ranges.

1.2 Hydrology

The humid, continental climate of Cape Cod is strongly influenced by the Atlantic Ocean. Proximity to the ocean results in mitigated temperature extremes. February is the coldest month

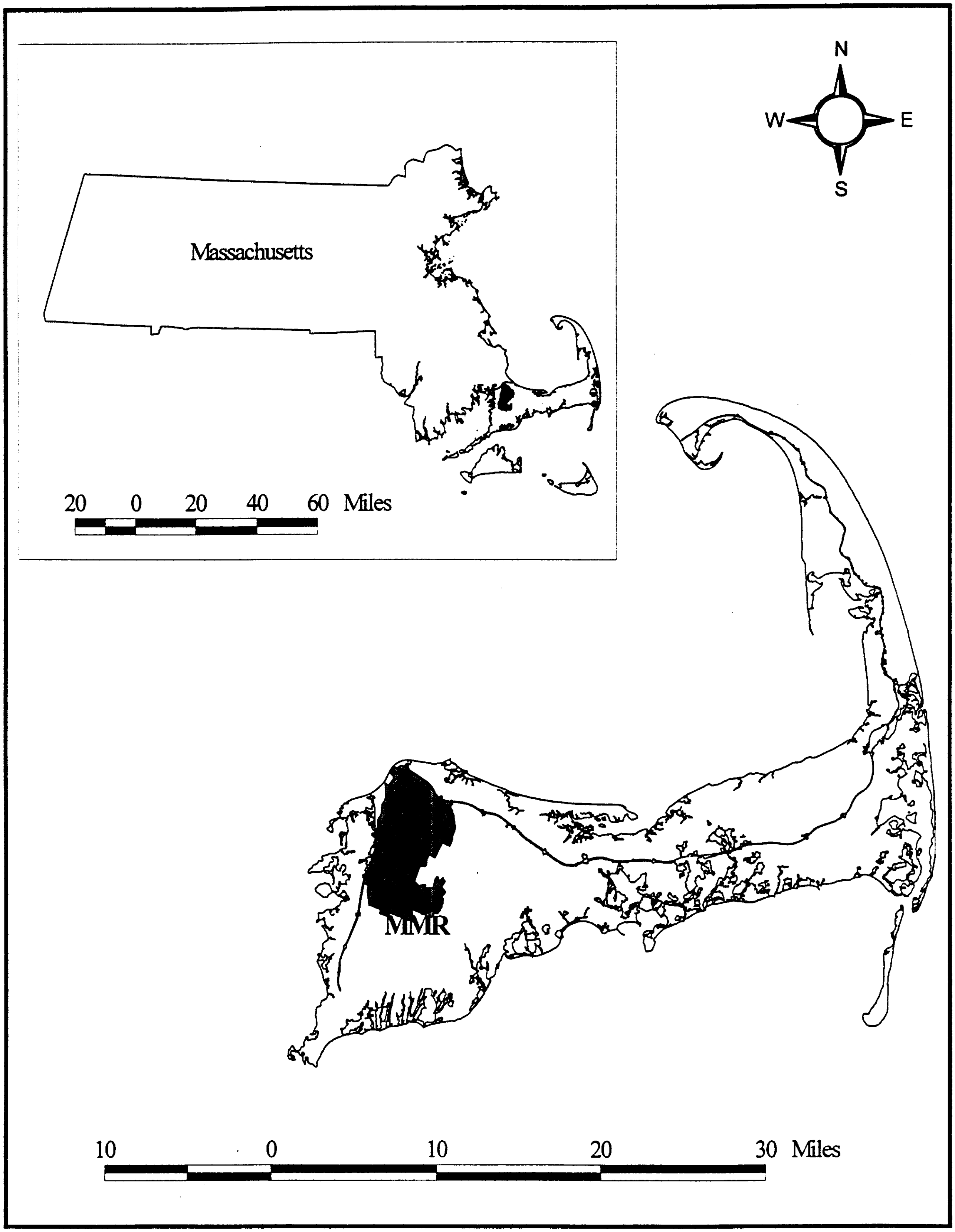


Figure 1-1: Location of MMR, Cape Cod, MA (Data obtained from Jacobs Engineering, 1998).

of the year, with daily temperatures ranging from an average minimum of 23 °F to an average maximum of 38 °F (ANG, 1993). July, the warmest month of the year, typically experiences average temperatures ranging from daily lows of 63 °F to daily highs of 78 °F (ANG, 1995). The oceanic influence results in warmer winters and cooler summers than those experienced in the inland areas of Massachusetts (ANG, 1995).

Cape Cod receives an average rainfall of 47.8 inches per year (ANG, 1995). The precipitation is distributed fairly evenly throughout the year, although a slightly higher portion of the precipitation occurs in the winter months (LeBlanc *et al.*, 1986). The one-year/24-hour rainfall event for Cape Cod is 2.7 inches (Baker *et al.*, 1997).

Due to the highly permeable sand and gravel deposits prevalent on Cape Cod, surface-water runoff is less than 1% of the total precipitation (LeBlanc *et al.*, 1986). Approximately 55% of the total precipitation is returned to the atmosphere via evaporation or transpiration by plants (LeBlanc *et al.*, 1986). The remaining 45% infiltrates to recharge the ground water (LeBlanc *et al.*, 1986).

Although ground water provides the main source of water for Cape Cod, approximately 4% of Cape Cod is covered by surface-water bodies. These surface-water bodies, mainly intermittent streams or kettle holes, receive a net recharge of approximately 18 inches per year from direct precipitation (ANG, 1995).

The prevailing winds along Cape Cod are heavily influenced by the Atlantic Ocean and the Gulf Stream. From November through March, the prevailing winds arise from the northwest, whereas, from April through October, the prevailing winds originate from the southwest (ANG, 1995). Average wind speeds range from 9 miles per hour in the summer months to 12 miles per hour throughout the remainder of the year. Episodic tropical or ocean storms can result in exceedingly high wind velocities, ranging from 40 to 100 miles per hour (ANG, 1995).

1.3 Hydrogeology and Topography

The geology of western Cape Cod was shaped during the Wisconsin period, 85,000 to 7,000 years B.P. (Before Present), of the Pleistocene epoch, with the advance and retreat of two glacial lobes that resulted in glaciofluvial sedimentation. To the north and west, the Buzzards Bay and Sandwich Moraines are composed mostly of glacial till. South is the Mashpee Pitted Plain, an outwash plain containing poorly sorted, fine- to coarse-grained outwash sands overlying finer-grained till and marine or lacustrine sediment. This lower layer of fine sediment has a hydraulic conductivity that is as much as five times less than that of the upper outwash layer, so that ground-water flow occurs mostly through the permeable upper layer. Seepage velocity within the sand and gravel outwash is estimated between 1 and 4.6 feet per day, with virtually no vertical flow. The entire plain is dotted with numerous kettle holes, bodies of water that resulted when large blocks of glacial ice, embedded in the sediment, melted. These ponds are maintained mostly by ground-water recharge and runoff.

The topography of the area can be characterized as a broad, flat, glacial outwash plain, dotted by kettle holes and other depressions, with marshy lowlands to the south, and flanked along the north and the west by recessional moraines and hummocky, irregular hills. Remnant river valleys cross the Mashpee Pitted Plain from north to south, while to the north and west the Buzzards Bay and Sandwich Moraines lend a higher degree of topographic relief.

1.4 Site History

Activities at the MMR began in 1911. Operational units at the MMR included the U.S. Air Force, U.S. Navy, U.S. Army, U.S. Marine Corps, U.S. National Guard, U.S. Army National Guard, and U.S. Coast Guard. Activities at the MMR have included troop development and deployment, fire-fighting, ordnance development, testing and training, aircraft and vehicle operation and maintenance, and fuels transport and storage. Most activities are associated with either army training, maneuvers, or military aircraft operations, maintenance, support, and associated functions. From 1955 to 1970, a substantial number of surveillance and air defense aircraft operated out of the ANG portion of the reservation. Since that time, the intensity of operations has decreased substantially.

Past releases of hazardous materials at the MMR have resulted in ground-water contamination in a number of areas. Documented sources of contamination include former motor pools, landfills, fire-fighting training areas, and drainage structures such as dry wells. Several major plumes of ground-water contamination have been found to be migrating from these source areas and have been defined during extensive ground-water investigations.

1.5 Demographics and Socio-Economic Impacts

The MMR is located on top of a recharge area that supplies water to all the towns surrounding the base. When the MMR was named a Superfund site by the Environmental Protection Agency in 1989, it became clear that the contamination was a threat to the public, as well as to the environment.

Sagamore Lens, the largest lens of the Cape Cod Aquifer, provides drinking water to over 70,000 homes and businesses in the towns of Sandwich, Falmouth, Mashpee, Barnstable, Bourne, and Yarmouth. The MMR itself has a yearly population of about 2000 people while the population of the surrounding towns fluctuates between the winter and summer seasons. During the off season of 1990, an average of 12.5 million gallons per day were supplied from the lens. Pumping rates double in the summer.

2. Massachusetts Military Reserve (MMR)

In 1978, the town of Falmouth detected detergents in a public water-supply well located south of the Massachusetts Military Reserve wastewater treatment plant. The United States Geological Survey (USGS) immediately began conducting ground-water investigations, and soon identified a ground-water plume extending south of the treatment plant and into Ashumet Valley. Subsequently, the Air National Guard (ANG) established an Installation Restoration Program (IRP) at Otis ANG Base. The IRP was initiated in 1982 with the purpose of identifying and evaluating potential hazardous waste sites at the MMR (MMRIRP, 1997m).

Between 1982 and 1985, investigations at the MMR revealed 73 contaminated soil and ground-water sites. Since 1985, five additional sites have been identified, bringing the total number of contaminated sites to 78. As of September 1996, the ANG and various regulators concluded that 31 of the 78 sites at the MMR pose no threat to the public nor the environment and therefore, require no further action (MMRIRP, 1997m). As a result of the investigations conducted at the base, seven major ground-water plumes have been identified:

- Fuel Spill-12 (FS-12)
- Storm Drain-5 (SD-5)
- Chemical Spill-10 (CS-10)
- Landfill-1 (LF-1)
- Fuel Spill-28 (FS-28)
- Ashumet Valley
- Chemical Spill-4 (CS-4)

Figure 2-1 illustrates the location extent of the plumes relative to the base.

In 1993, the ANG, in conjunction with the United States Environmental Protection Agency (USEPA), Massachusetts Department of Environmental Protection (MADEP), and various

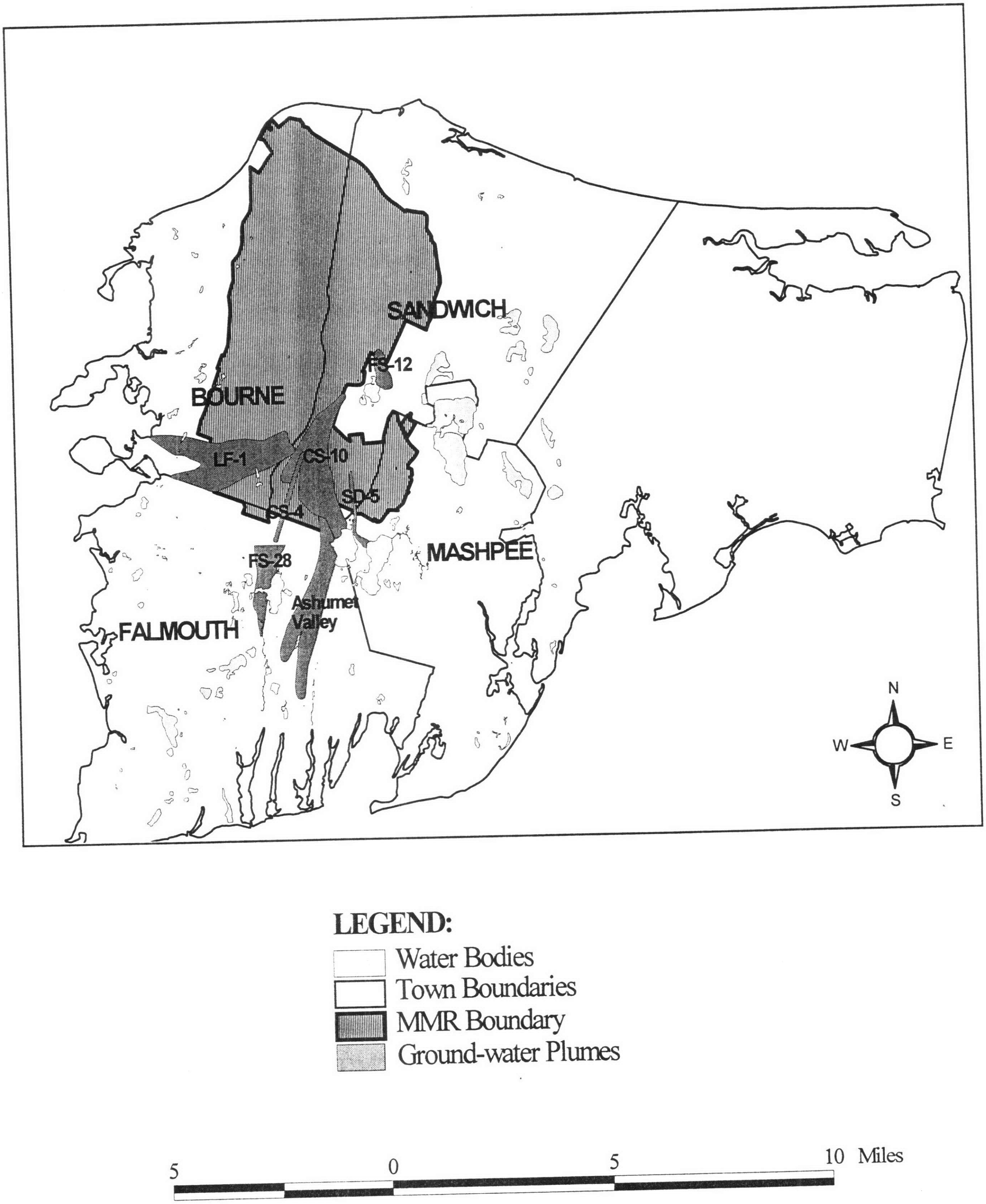


Figure 2-1: Location and extent of the seven major ground-water plumes identified at the MMR.

citizen groups, began addressing the ground-water plumes at the MMR. These groups worked in concert to develop a containment program that called for 100%, simultaneous remediation of the ground-water plumes. However, evaluation of the design in 1996 revealed that simultaneous containment was not possible without adversely impacting the ecosystems of Cape Cod due to excessive water-table drawdown. As a result, a Technical Review and Evaluation Team (TRET) was established to evaluate alternatives to the 100%, simultaneous containment design. In May 1996, TRET concluded that the ground-water plumes would undergo a phased remediation approach (MMRIRP, 1997m). In July 1996, a Strategic Plan was published that outlined the Plume Response Project (PRP). This project defined the remedial action and construction schedule for each of the plumes at the site. However, the remedial action outlined in the PRP is merely "interim action" (Jacobs, 1997p). The PRP is not the final solution for the ground-water plumes, but rather a short-term solution preventing further contamination. The long-term solutions, those that address the bodies of the plumes rather than their advancing fronts, are still under investigation.

2.1 Fuel Spill-12

Figure 2-2 illustrates the current extent and location of the Fuel-Spill 12 (FS-12) ground-water plume. The plume is approximately 4,800 feet long and has a maximum width of 2,000 feet. It ranges in thickness from 60-130 feet, and is approximately 90 feet below ground surface (Jacobs, 1997t). It mainly affects the area immediately south of the base, abutting Snake Pond, Sandwich, Massachusetts (Figure 2-2).

The primary contaminants of the FS-12 plume are benzene and ethylene dibromide (EDB). Both compounds are fuel components, however EDB was mainly used in leaded gasoline to prevent lead build-up in engines (MMRIRP, 1997g). Benzene was detected at a maximum concentration of 2000 micrograms per liter (μg/L) and EDB was detected at a maximum concentration of 300 μg/L (Jacobs, 1997c). Table 2-1 lists the chief contaminants in the FS-12 plume, along with the

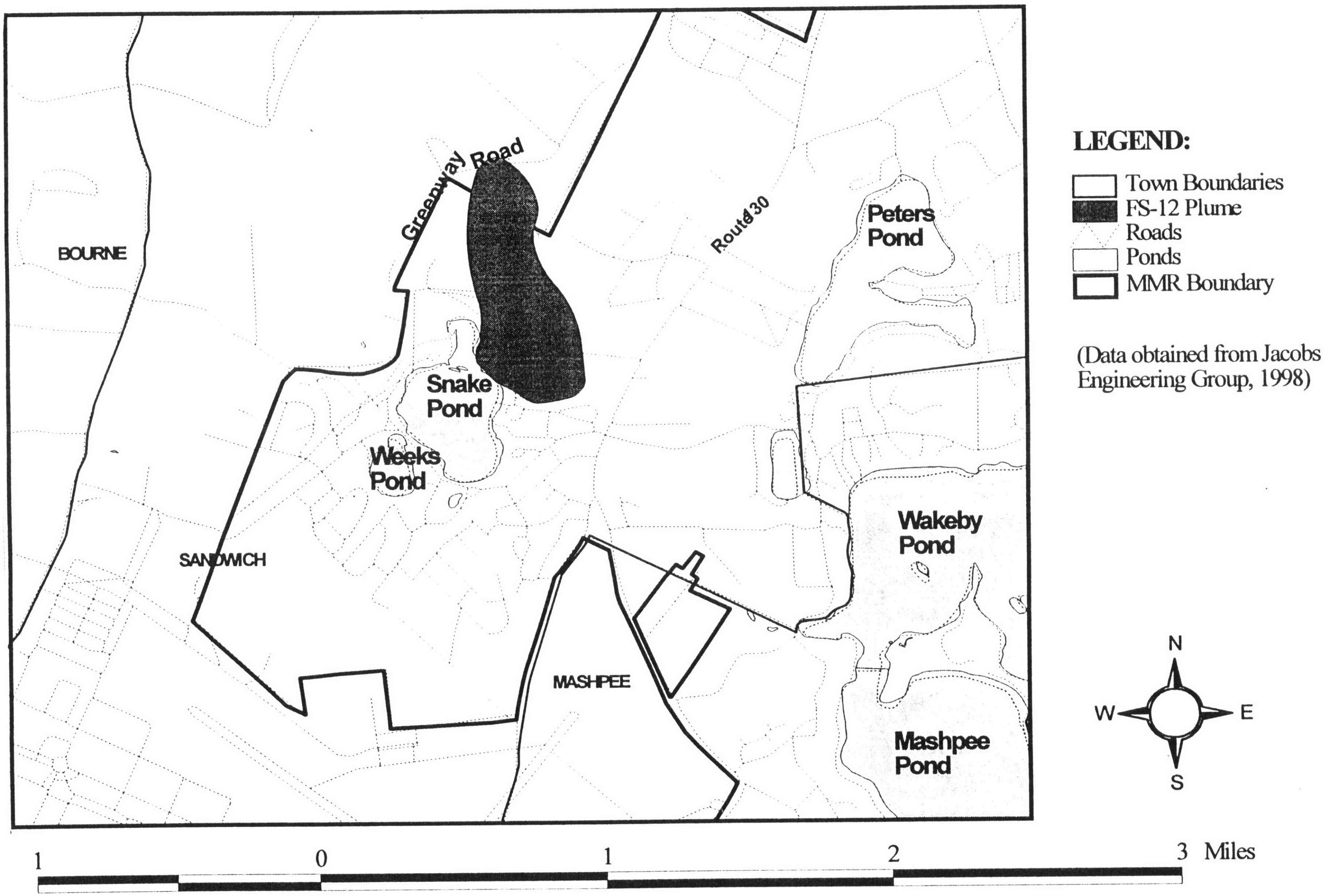


Figure 2-2: Location and extent of FS-12 ground-water plume, MMR, Cape Cod, MA.

60%-design-based concentrations. The 60%-design concentrations represent the average conditions found within the plume, with a safety factor applied to correct for any error in concentration underestimation. All of the contaminants detected in the plume exceed their Maximum Contaminant Level (MCL), as defined by the United States Environmental Protection Agency (USEPA). The MCLs regulate the concentration of organic and inorganic contaminants in public drinking water supplies (Jacobs, 1997a). Table 2-1 lists the MCLs for iron and manganese even though these inorganic constituents do not pose a health risk. Their MCL was defined for aesthetic reasons, namely taste and appearance.

Table 2-1: Chemical composition of ground-water plume FS-12.

Contaminant	60%-design concentration[1] (μg/L)	MCL[1] (μg/L)	Cleanup Level[2] (μg/L)
Benzene	60	5	0.1
EDB	8.2	5	0.02
Iron	526	300	300
Manganese	65	50	0.01

[1] (Jacobs, 1996a).
[2] Cleanup levels at the MMR are typically set at the Practical Quantitation Limit (PQL) or at the MCL, whichever is more applicable. The PQL is defined by the EPA as the lowest level at which a chemical can be accurately and reproducibly quantitated (Jacobs, 1996b).

The source of the FS-12 ground-water plume was a leak in an aviation fuel pipeline located along Greenway Road (Figure 2-2) (MMRIRP, 1997g). Although the pipeline is no longer in use, back in the early 1970s the pipeline supplied aviation gas (AVGAS) and jet-propellant-4 (JP-4) to the MMR (Jacobs, 1997t). The break occurred in 1972 and released approximately 70,000 gallons of aviation fuel into the soil (MMRIRP, 1997g).

Cleanup of the FS-12 plume is divided into two projects: (1) source cleanup, and (2) aquifer cleanup. The source cleanup focuses on reducing the total load of contaminants to the aquifer. The source area at FS-12 is currently being treated by an air sparging and vapor extraction system. An air sparging and vapor extraction system requires an extraction well that channels air bubbles into the aquifer. As the contaminants contact the air bubbles, they volatize into the air and rise up through the well into an above-ground collection system. From the collection system, the vapor is passed through a catalytic oxidizer, which uses metal and heat to mineralize the contaminants, yielding carbon dioxide and water. The contaminant stream is then passed through activated carbon filters to remove any fuel compounds still remaining. The fuel compounds adsorb to the activated carbon granules as they pass through the system. As a result, the contaminants are filtered out of the water, rendering clean water that can be discharged into the aquifer. This system has operated at FS-12 since October 1995 and the Air Force Committee for Environmental Excellence (AFCEE) anticipates this phase of remediation will conclude in January 1998 (MMRIRP, 1997g).

The aquifer cleanup project focuses on restoring the aquifer and preventing the contaminants from migrating further downgradient. AFCEE is using an extraction, treatment, reinjection (ETR) system to remediate the FS-12 ground-water plume. An extraction, treatment, and reinjection (ETR) system, illustrated in Figure 2-3, is an example of a pump-and-treat remediation technology. As depicted in the figure, two wells are required; one well extracts the water from the aquifer, supplying it to the above-ground treatment facility, and the second well returns the water to the aquifer after it is treated. The extraction wells are usually placed in series and the location of this extraction fence varies as a function of removal requirements. If the goal of remediation is to reduce the contaminant mass within the plume, the wells are placed within the center of the plume. Whereas, if the goal is to protect drinking water sources downgradient, the extraction fence is located strategically to intercept the plume. Once the water is extracted, it is subject to a series of unit treatment processes. The treatment process typically prescribed for treating organic contaminants is granular activated carbon filters. Auxiliary treatment processes may be used in conjunction with the carbon vessels to remove inorganic contaminants and ensure treatment standards are met. After the water is treated, it is returned to the aquifer via a series of reinjection wells, located downgradient of the extraction fence, beyond the footprint of the plume.

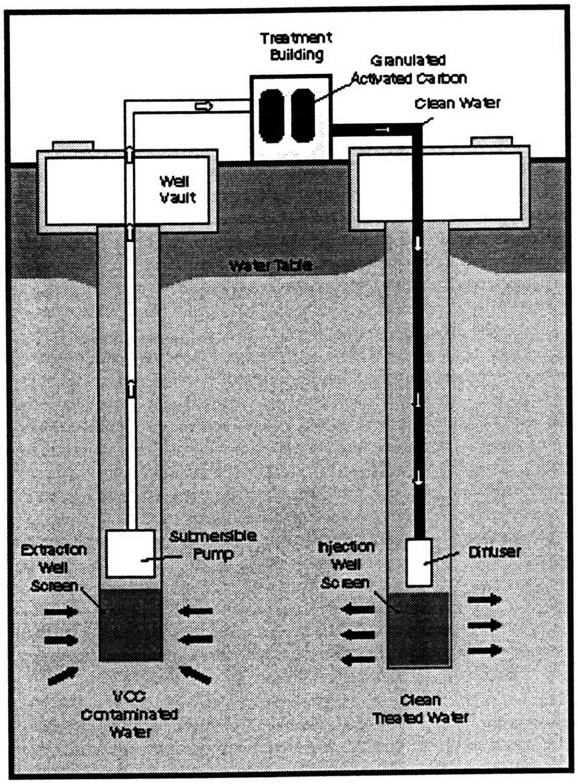


Figure 2-3: Components of an ETR system (Jacobs, 1997q)

The ETR system for the FS-12 plume is composed of 25 extraction wells, a treatment facility, and 23 reinjection wells (MMRIRP, 1997g). The treatment facility uses a series of unit treatment operations to remove the contaminants from the ground water (Operational Technologies Corporation, 1995):

- Six greensand filters: reduce the amount of total suspended solids (TSS), iron, and manganese present within the water.
- Ten Ultraviolet/Oxidation (UV/Ox) Reactors: degrade EDB and benzene. The UV/Ox reactors remove 90% of the organics present within the water (Jacobs, 1997c).
- Three Carbon Filters: remove remaining contaminants to levels below MCLs.

The resulting clean water is then reinjected into the aquifer.

Construction of this system was broken into two phases. Phase I construction began in November 1996 and went on-line in September 1997. The wells are pumping at a total rate of 850 gallons per minute (gpm), however, phase I will not capture the entire plume. Phase II will address the area of the plume not contained by phase I (MMRIRP, 1997g). Construction of phase II is scheduled for May 1998 (Jacobs, 1997c). Preliminary designs indicate that the total pumping rate of the phase II extraction wells will be approximately 300 gpm (MMRIRP, 1997g). The ETR system for the FS-12 plume is designed for a 20-year operating life.

2.2 Storm Drain-5

Figure 2-4 illustrates the current extent and location of the storm drain 5 (SD-5) ground-water plume. The plume is approximately 10,000 feet long, is a maximum of 1,000 feet wide, and ranges in thickness from 20 to 100 feet. The shape and chemical composition of the SD-5 plume varies with a north-south trend, therefore, it is commonly fragmented into two plumes: SD-5 north and SD-5 south. SD-5 south is approximately 4,500 feet long, roughly 1,000 feet wide and has an average thickness of 50 feet (MMRIRP, 1997i). SD-5 north is similar, yet has a wider range in thickness. Figure 2-4 distinguishes the north and south plumes.

The primary contaminants at SD-5 north are trichloroethylene (TCE), perchloroethylene (PCE), and 1,2-dichloroethylene (1,2-DCE). These cleaning solvents have an extensive history of use at the MMR. TCE was detected at a maximum concentration of 82 μg/L, PCE at 6 μg/L, and 1,2-DCE at 220 μg/L (Jacobs, 1997d). Table 2-2 lists the major contaminants detected at SD-5 north, their 60% design-based concentrations, and their MCLs. According to Table 2-2, none of the contaminants exceeds its MCL. SD-5 south is similar in chemical composition to SD-5 north, except that the concentrations detected in the southern portion of the plume are much higher than in the north. The maximum concentration of TCE in SD-5 south was 2,700 μg/L, and the maximum concentration of PCE was 86 μg/L (Jacobs, 1997d).

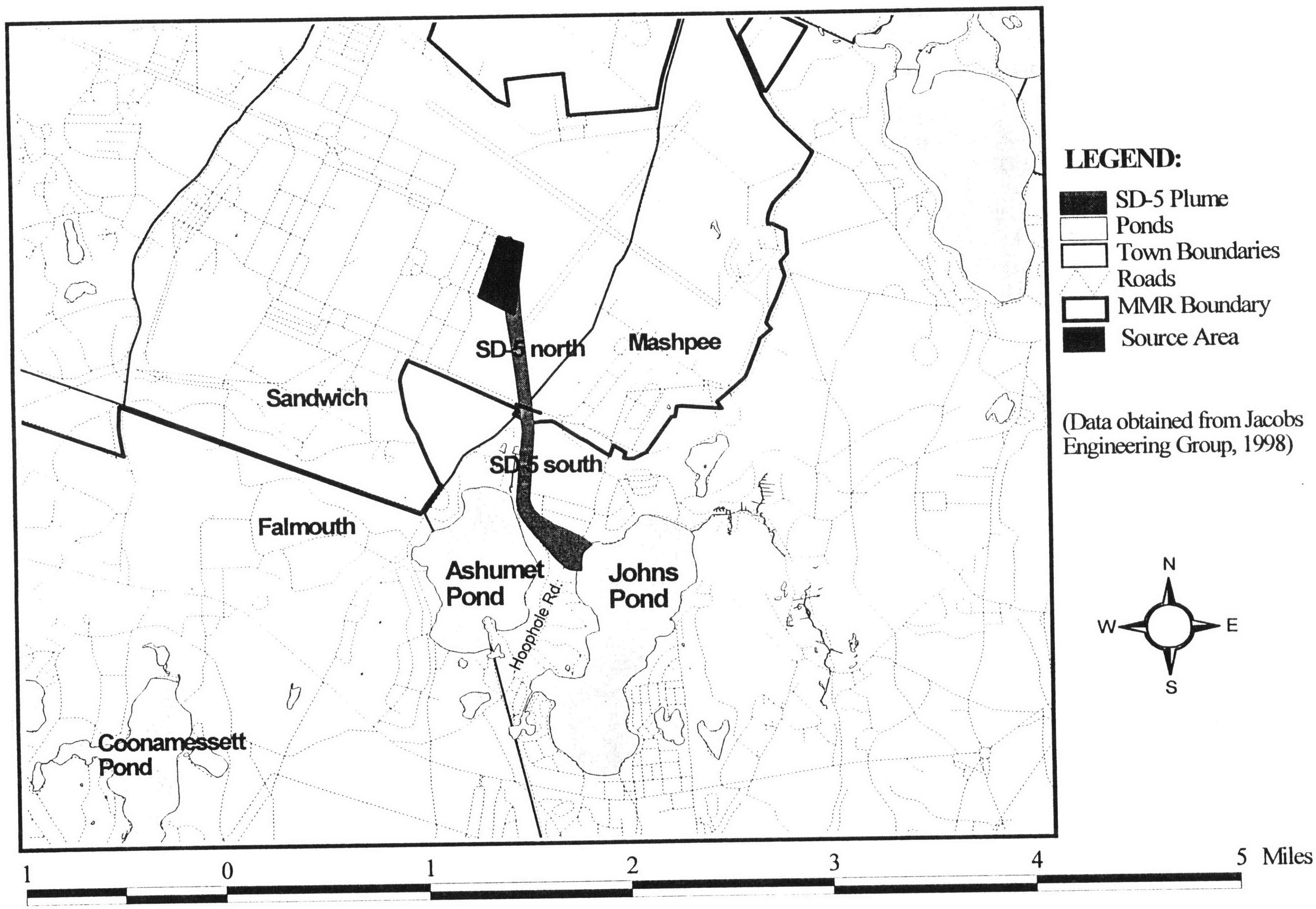


Figure 2-4: Location and extent of ground-water plume SD-5, MMR, Cape Cod, MA.

Table 2-2: Chemical composition of ground-water plume SD-5.

Contaminant	60% design concentration[1] (µg/L)	MCL[2] (µg/L)	Cleanup Level[3] (µg/L)
Benzene	0.78	5	0.1
EDB	1.1	5	0.02
PCE	0.77	5	0.3
TCE	3.8	5	0.03
Iron	243	300	300
Manganese	44	50	0.01
Lead	4.2	15	15[4]

[1] (Jacobs, 1996b).
[2] (Jacobs, 1996a).
[3] Cleanup levels at the MMR are typically set at the Practical Quantitation Limit (PQL) or at the MCL, whichever is more applicable. The PQL is defined by the EPA as the lowest level at which a chemical can be accurately and reproducibly quantitated (Jacobs, 1996b).
[4] EPA action level. No MCL has been declared (Jacobs, 1996b).

There are several sources that contributed to the contamination resulting in the SD-5 plume. The main source is storm drain 5, which received runoff from several military and industrial sites at the MMR (MMRIRP, 1997i). Many of the buildings located within proximity to storm drain 5 are also suspected to have contributed to the ground-water plume.

Due to the fragmented nature of this plume, the cleanup of SD-5 has been divided into three projects: (1) source cleanup, (2) SD-5 north cleanup, and (3) SD-5 south cleanup. The Air Force's proposed plan for the source cleanup at SD-5 is currently under regulatory review. The plan of remediation requires the excavation of the contaminated soil. Rather than remove the contaminants from the soil, the soil will be mixed with gravel and asphalt and then used to pave roads at the MMR (MMRIRP, 1997i). The soil-asphalt mixture contains the contaminants, preventing future migration.

In February 1997, construction began on the ETR system for SD-5 north. The system is composed of 10 extraction wells pumping at a combined rate of 350 gpm, 8 reinjection wells, and an activated carbon treatment facility (MMRIRP, 1997i). The system became operational in August 1997 and preliminary sampling indicates that the system is successfully remediating the plume (MMRIRP, 1997i).

The AFCEE, EPA, and MADEP serve as the remedial project managers for all of the plumes at the MMR. They recently decided on using recirculating well technology (RWT) for the remediation of SD-5 south.

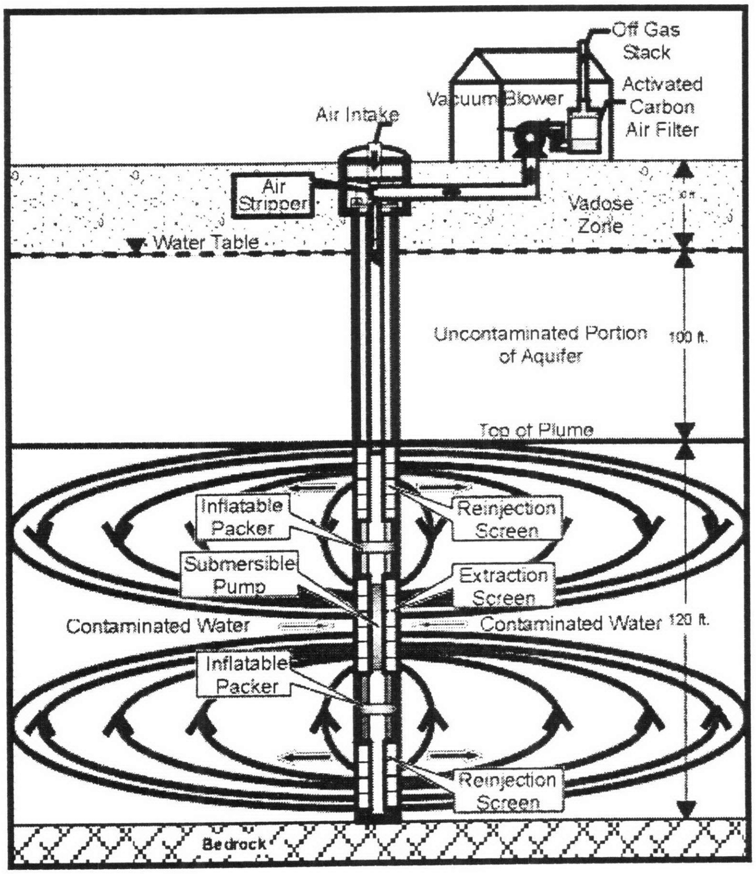


Figure 2-5: Components of an RWT system (Jacobs, 1997q).

Figure 2-5 illustrates a typical RWT system. As depicted in the figure, there is only one well required to extract and reinject the ground water. The ground water enters at the middle of the well screen and is pumped up through the well against a stream of pressurized air. The air stream forms bubbles, promoting the volatilization of the volatile organic compounds (VOCs) present within the ground water. The VOC vapors are carried to the top of the well, where they undergo treatment, mainly carbon adsorption. The cleaned water is pumped back into the well, and out into the ground-water aquifer at a either a shallower or deeper depth than it was extracted. The two reinjection zones create a zone of circulation around the well, promoting the capture of contaminated water (MMRIRP, 1997h). Since water is continuously flowing through the well, equilibrium is established, preventing water-table drawdown.

The design and implementation of the remediation system is in the preliminary stages, therefore, the precise location and number of wells for the system has yet to be determined (MMRIRP, 1997j). It is estimated three wells will be located within the body of the plume, in a formation aligned in the direction of flow (axial) (MMRIRP, 1997j). Two additional recirculating wells will be located along Hoophole Road to provide auxiliary capture and reduce the contaminant mass loading into Johns Pond (Figure 2-4). The treatment efficiency of recirculating wells is approximately 90%, therefore, this technology may not reduce the contaminants to non-detectable limits (MMRIRP, 1997j). RWT does not treat EDB effectively, so in the event of EDB detection at levels requiring removal action, supplementary treatment systems must be installed.

Approximately 40% of the plume is not captured by the proposed remediation plan. The uncaptured portion will discharge to Johns Pond, Ashumet Pond, and the Quashnet River, however, there is no implication that the surface-water bodies will experience an adverse environmental or ecological impact (MMRIRP, 1997j).

The total capital cost of the proposed system is estimated to be $9 million dollars. Annual operation and maintenance cost is projected to be $1 million dollars. Life-cycle cost, including capital cost, over 20-years of operation is estimated to be $26 million dollars (MMRIRP, 1997j).

2.3 Chemical Spill-10

Figure 2-6 illustrates the current extent and location of the Chemical Spill-10 (CS-10) ground-water plume. The CS-10 plume is roughly 17,000 feet long and a maximum of 4,000 feet wide. It varies in thickness, with a maximum of 140 feet, is approximately 120 feet below ground surface, and 60 feet below the water table (MMRIRP, 1997o). The plume primarily impacts the south/central area of the base, however, the eastern lobe of CS-10 is migrating off-base, towards

Ashumet Pond. Investigations have been initiated to determine if the CS-10 plume flows beneath Ashumet Pond or if it discharges into the Pond.

The chief contaminants in CS-10 are TCE, PCE, and 1,2-DCE (MMRIRP, 1997o). TCE has the largest extent in which its concentration exceeds its MCL. The western lobe of CS-10 has TCE concentrations as high as 400 μg/L, and the eastern lobe has TCE 'hot-spots' exceeding 3200 μg/L (Jacobs, 1997a).

The primary source responsible for the CS-10 plume is the former BOMARC Missile Site and current Unit Training Equipment Site (UTES) located at the MMR (Figure 2-6) (MMRIRP, 1997o). The BOMARC Missile Site was operated between 1962 and 1973 to serve as a maintenance site for ground-to-air missiles, fuel and engine systems, and power plant operations. The activities conducted at the BOMARC Missile Site produced extensive amounts of waste as evident by the types of chemicals detected (halogenated and non-halogenated hydrocarbons, battery electrolyte, and degradation products of rocket fuel). UTES has been in operation since 1978. This site has a history of contamination spills, but in December 1995 a pollution prevention program was initiated to prevent future contamination problems. Eleven other potential sources have also been identified along the western and central perimeter of the plume (Jacobs, 1997a). Source cleanup for the CS-10 plume has already been initiated. More than 180 former waste/disposal storage facilities believed to be contributing to the CS-10 plume have been removed, and all the resulting contaminated soil has been excavated.

The remedial managers recently agreed by consensus on using an ETR system to remediate the CS-10 plume. The design and implementation of this remediation alternative is only in the preliminary stage, therefore, the exact location and number of wells has yet to be concluded. It is estimated that the system will be comprised of a total of 94 extraction and reinjection wells, pumping at a total rate of 6.9 million gallons per day (Mgd) (MMRIRP, 1997a). It is estimated that the system must operate for at least 50 years (MMRIRP, 1997b). The major components of the ETR system are (MMRIRP, 1997a):

- Sandwich Road extraction treatment (ET) fence and east reinjection fence — designed to capture the portion of the plume just north of Sandwich Road and prevent further migration into Ashumet Pond.

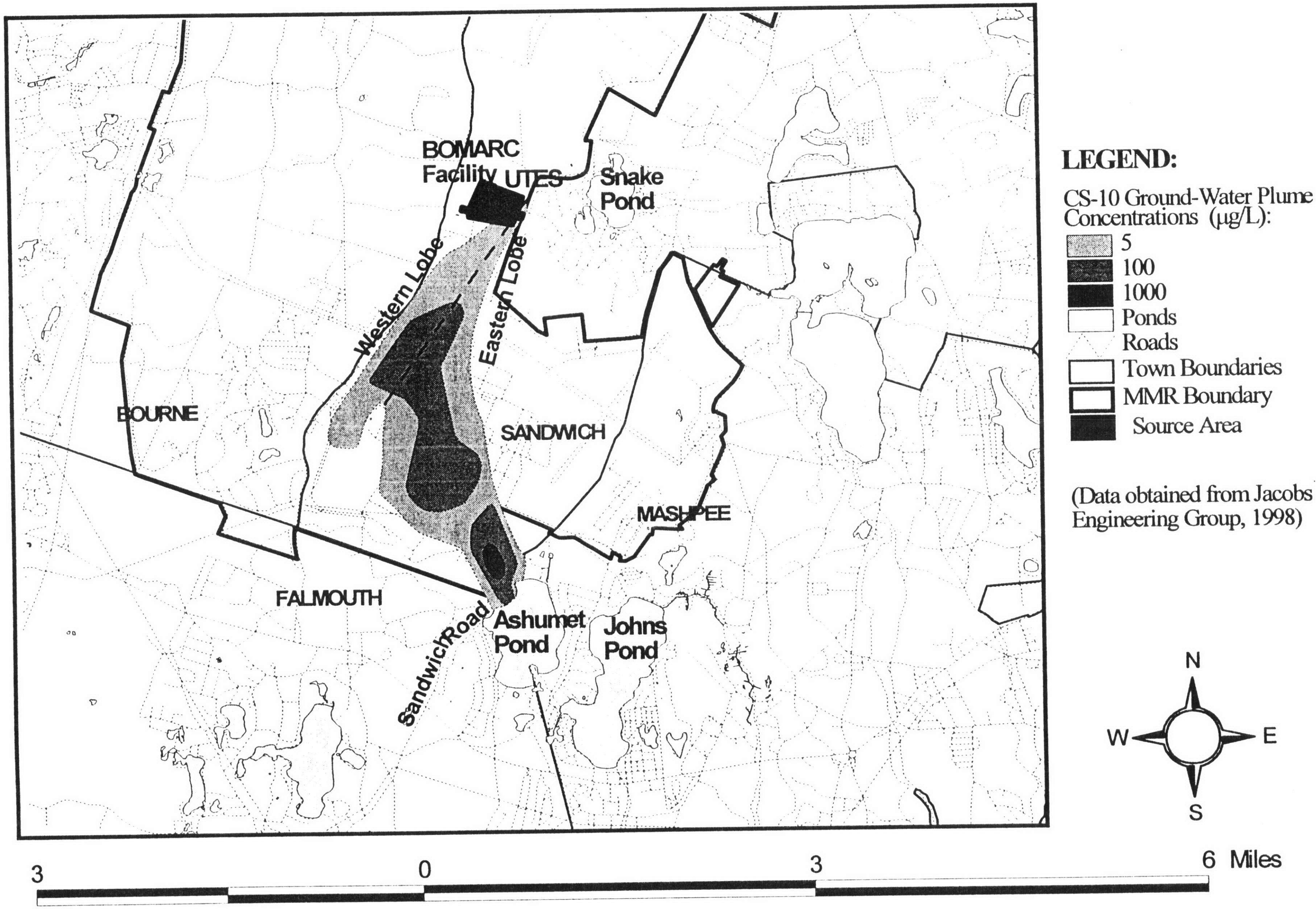


Figure 2-6: Location and extent of CS-10 ground-water plume, MMR, Cape Cod, MA

- Southern ET fence and main reinjection fence — designed to prevent further migration of the CS-10 plume and protect the existing and future water supplies downgradient.

- Southwest ET fence and west reinjection fence — designed to prevent further migration of the CS-10 plume and protect the uncontaminated portion of the aquifer downgradient. It is also designed capture the upgradient segments of ground-water plumes CS-4 and FS-28.

The design is proposed to capture and treat 98% of the contaminant mass. The MMRIRP believes the 2% not captured poses a low risk to human health and minor ecological impacts (MMRIRP, 1997d).

The total capital cost for the proposed system is approximately $39.8 million dollars. Annual operation and maintenance cost is projected to be $3.4 million dollars. Life cycle cost, including capital cost, based on 20 years of operation is estimated to be approximately $108 million dollars (MMRIRP, 1997b).

2.4 Landfill-1

Figure 2-7 illustrates the current extent and location of the landfill-1 (LF-1) ground-water plume. This plume is approximately 16,000 feet long and has a maximum width of 5,500 feet. The average thickness of the plume is 35 feet. The LF-1 plume is approximately 150-200 feet below ground surface and is generally 100-150 feet below the water table (Jacobs, 1997r).

The main contaminants present in the LF-1 plume are TCE, PCE, and carbon tetrachloride (CCl_4) (Jacobs, 1997r). Table 2-3 summarizes the principal contaminants detected in the plume during the remedial investigation (CDM, 1996). All of the chemicals listed in Table 2-3 exceeded their MCL. Generally, TCE, PCE, and CCl_4 exceed their MCL throughout the southern portion of the plume, whereas, only TCE and PCE exceed their MCL throughout the northern portion (CDM, 1996). Other contaminants such as dichloroethane (1,1-DCA), 1,1-DCE, cis-1,2-DCE, BTEX (benzene, toluene, ethylbenzene, and xylene), 1,4-dichlorobenzene (1,4-DCB), and various inorganic compounds have also been detected in LF-1 (Jacobs, 1997t).

The source of the LF-1 plume was the MMRs main landfill. Unregulated disposal occurred at the landfill from 1940 to 1984 (Jacobs, 1997s). Typical wastes deposited in the landfill consisted of general refuse, blank small-arms ammunition, paints and paint thinners, hospital waste, herbicides, solvents, and municipal sewage sludge (CDM, 1996). Rainwater soaked through the waste at the landfill and carried leachate underground, into the aquifer. The landfill cells generating the leachate were capped in 1995 to prevent further contamination (Jacobs, 1997r).

Table 2-3: Chemical composition of ground-water plume LF-1.

Contaminant	Maximum Concentration[1] (μg/L)	MCL[2] (μg/L)
PCE	65	5
TCE	64	5
vinyl chloride (VC)	8.5	5
CCl_4	60	5
1,4-DCB	14	5

[1] (CDM, 1996).
[2] (Jacobs, 1996b).

The remedial project managers agreed upon designing an ETR system to remediate the portion of LF-1 east of Route 28 while concurrently exploring the effectiveness of monitored natural attenuation (MMRIRP, 1997k). Monitored natural attenuation will be employed for the portion of the plume west of Route 28.

AFCEE is seeking to demonstrate the efficacy of using monitored natural attenuation at the LF-1 plume. Natural attenuation is the process by which natural physical, chemical, biological transport mechanisms reduce contaminant levels. There are five main mechanisms involved in natural attenuation (MMRIRP, 1997h):

- ***biodegradation:*** microorganisms metabolize the contaminants, typically forming less harmful by-products.
- ***chemical stabilization:*** a chemical process whereby the contaminants undergo reactions that reduce the mobility of the contaminant within the aquifer.
- ***dispersion:*** a physical process that is responsible for the mixing of the contaminant due to fluid flowing through a porous media.

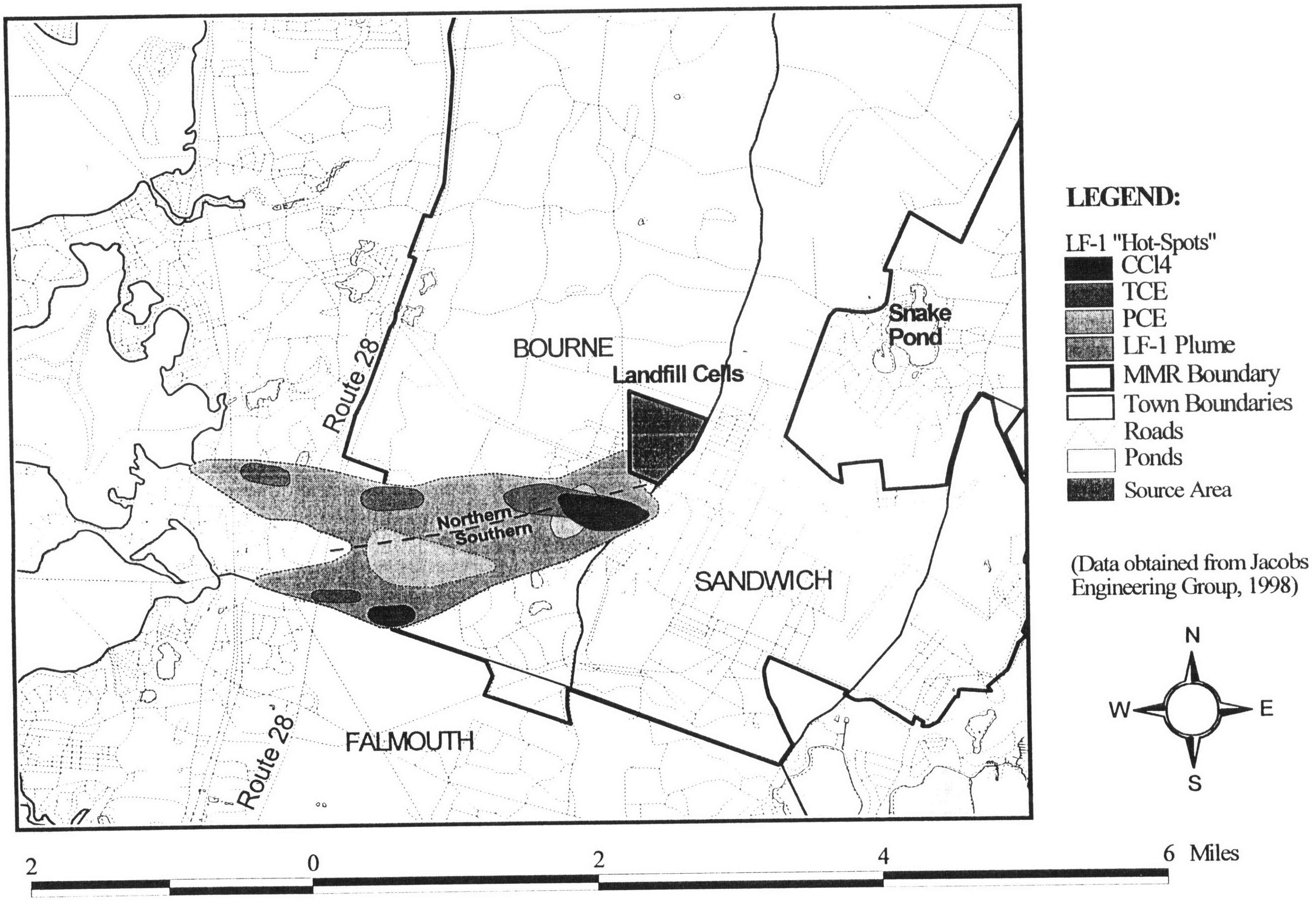


Figure 2-7: Location and extent of the LF-1 ground-water plume, MMR, Cape Cod, MA.

- ***sorption:*** the attachment of the contaminant to another substance, typically soil grains.
- ***volatilization:*** evaporation; the phase transfer from liquid to vapor.

These processes may reduce the total mass of contaminant, degrade the toxicity of the contaminant, or diminish the mobility of the contaminant through the soil column/aquifer.

The conditions at the LF-1 plume, namely the low contaminant concentrations and the lack of adverse impacts on human health or drinking water sources, make it an ideal test-site for natural attenuation (MMRIRP, 1997k). Upon completion of their investigation, the AFCEE submitted the results to the EPA and Massachusetts Executive Office of Environmental Affairs and Department of Environmental Protection (EOEA/DEP) for regulatory review. If monitored natural attenuation is not deemed a viable remediation solution for the eastern portion of LF-1, an ETR system will be constructed. It will be comprised of an extraction/treatment fence aligned perpendicular to the direction of flow, pumping at a total rate of 5.2 Mgd (MMRIRP, 1997l). Under this design, approximately 13% of the plume will not be captured (MMRIRP, 1997l).

2.5 Fuel Spill-28

Figure 2-8 illustrates the current location and extent of the Fuel Spill 28 (FS-28) ground-water plume. The plume is roughly 9,000 feet long, has a maximum width of 3,000 feet and varies in thickness up to 100 feet (MMRIRP, 1997b).

The main contaminant of the FS-28 plume is EDB. It has been detected at levels of approximately 23 μg/L (MMRIRP, 1997e). The MCL for EDB is 5 μg/L, however, cleanup levels are typically defined at 0.02 μg/L (Jacobs, 1996b).

The source of this plume has yet to be identified. Preliminary investigations imply the source may be near the Crane Wildlife Management Area (MMRIRP, 1997e). The plume is flowing

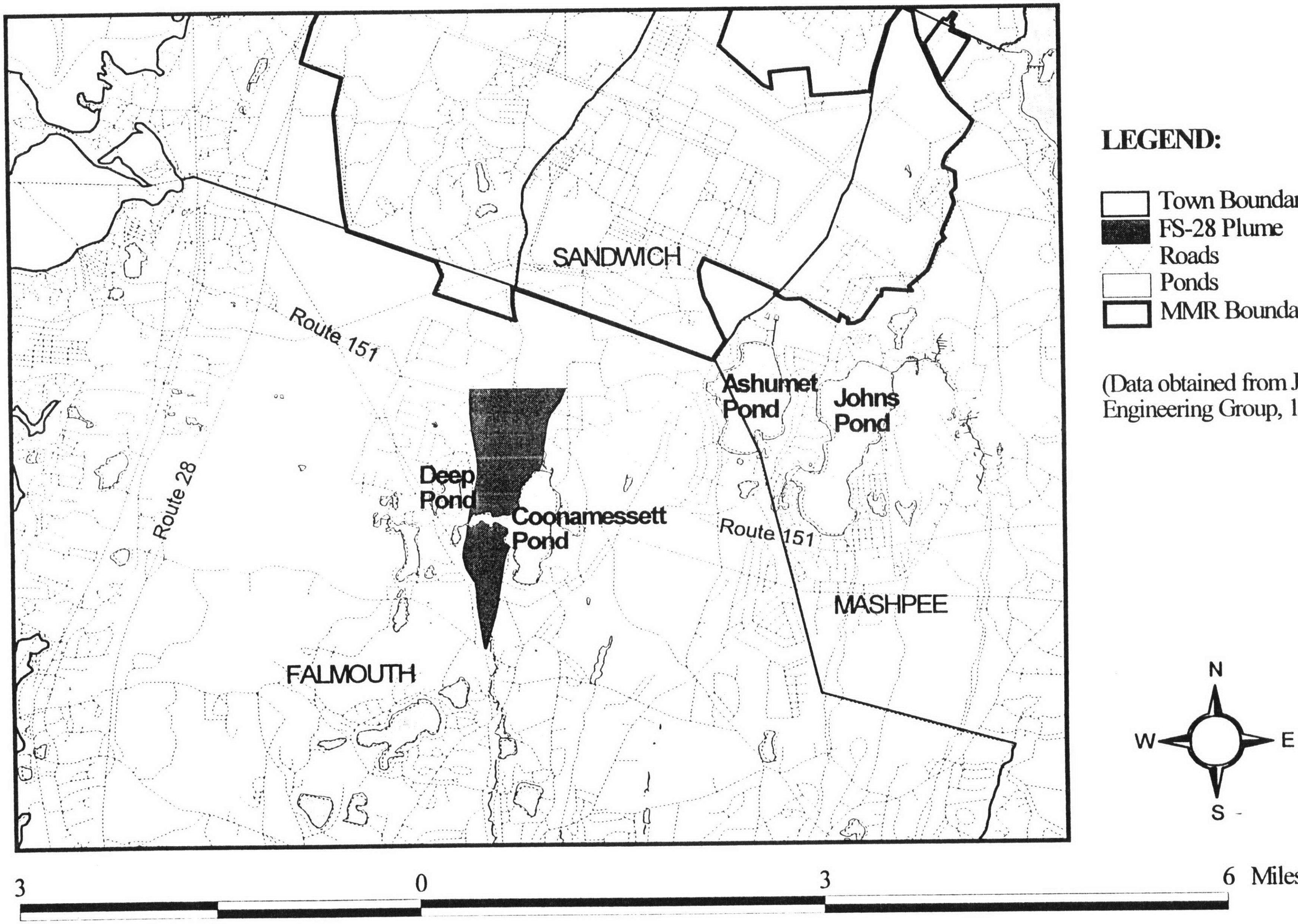


Figure 2-8: Location and extent of the FS-28 ground-water plume, MMR, Cape Cod, MA.

under the Coonamessett Pond, and EDB has been detected in the Coonamessett River as far south as Route 28 (Figure 2-8). The lower section of the plume is moving south, towards the town of Falmouth (MMRIRP, 1997e).

Due to the uncertainty regarding the source and full extent of the plume, a remediation scenario has not been identified yet. An extraction well has been installed near the toe of the plume, and is designed to pump at a total rate of approximately 800 gpm (MMRIRP, 1997e). Additional analyses need to be conducted to ascertain whether or not supplementary extraction wells will be needed to contain the plume.

2.6 Ashumet Valley

Figure 2-9 illustrates the current location and extent of the Ashumet Valley ground-water plume. It is the largest plume at the MMR, with a length of 20,000 feet and a maximum width of 4,500 feet. It is generally 40 feet thick, 70 feet below ground surface, and 60 feet below the water table (MMRIRP, 1997n).

The primary contaminants in the Ashumet Valley plume are TCE, PCE, and 1,2-DCE. Maximum concentrations of TCE have been measured at 79 μg/L, PCE at 180 μg/L, and 1,2-DCE at 1200 μg/L (Jacobs, 1997b). Benzene and EDB have also been detected sporadically throughout the plume at concentrations exceeding their MCL. Several other organic compounds, namely fuel-related contaminants, have been observed in the plume (Jacobs, 1997t). Elevated concentrations of inorganic compounds, such as nitrite, nitrate, phosphorous, boron, arsenic, iron, and manganese have also been detected throughout the plume, but at levels below their MCLs (Jacobs, 1997b). Two sources are mainly responsible for the Ashumet Valley ground-water plume. The inorganic compounds are mainly attributable to the MMR's former Sewage Treatment Plant (STP). The solvents and fuel-related contaminants primarily originated from the former Fire Training Area-1 (FTA-1), although the STP is also responsible for some of the contaminants (Figure 2-9) (Jacobs, 1997t). The MMR's STP consisted of primary and secondary treatment processes, sand infiltration beds, and sludge drying beds. From 1941 through the mid-

1960s, the dewatered residuals were disposed of in a wooded area within close proximity to the plant. The STP is suspected of supplying elevated levels of volatile organic compounds (VOCs), inorganics, and sewage-related contaminants to the Ashumet Valley ground-water system (Jacobs, 1997b). The FTA-1 operated between 1958 to 1985, at which time it was forced to close due to air-emission permitting problems. Until 1983, the activities at the site consisted of igniting flammable materials in an unlined, open pit, and then extinguishing the fires with foam or dry chemicals (Jacobs, 1997b). After 1983, the flammable materials were applied to a concrete pad in the center of the site. The flammable materials ranged in composition from jet/motor/diesel fuels to solvents and oils. The substances used to extinguish the fires included liquid chlorobromethane, carbon-dioxide, protein foam, and an aqueous film-forming foam (Jacobs, 1997b).

The remediation of the Ashumet Valley Plume is two-fold; the cleanup of the source, and the cleanup of the aquifer. Treatment of the source responsible for the plume began in June 1995. The soil contaminants detected and removed consisted of petroleum hydrocarbons (TPH), fuel-related VOCs, chlorinated solvents, pesticides, polychlorinated biphenyls (PCBs), and dioxins (Jacobs, 1996b). Over 20,000 tons of contaminated soil were excavated and cleaned. The soil cleanup phase was completed in September 1997 (MMRIRP, 1997n). The former sewage treatment beds were decommissioned in December 1995, and a feasibility study to select a remediation process for these beds is underway (MMRIRP, 1997f).

The remedial project managers agreed to use an ETR system to clean the aquifer. Two main extraction treatment fences will be installed to maximize plume containment. One fence will extend through the center of the plume in an axial formation. The second extraction treatment fence will be located along the northwest shore of Ashumet Pond to help prevent contaminant loading into the pond (MMRIRP, 1997f). It is estimated that 75 extraction/reinjection wells will be installed to contain the plume, with a combined pumping rate of 2.8 Mgd (MMRIRP, 1997c). Approximately 30% of the plume mass will not be contained, but rather will undergo natural attenuation (Jacobs, 1997b).

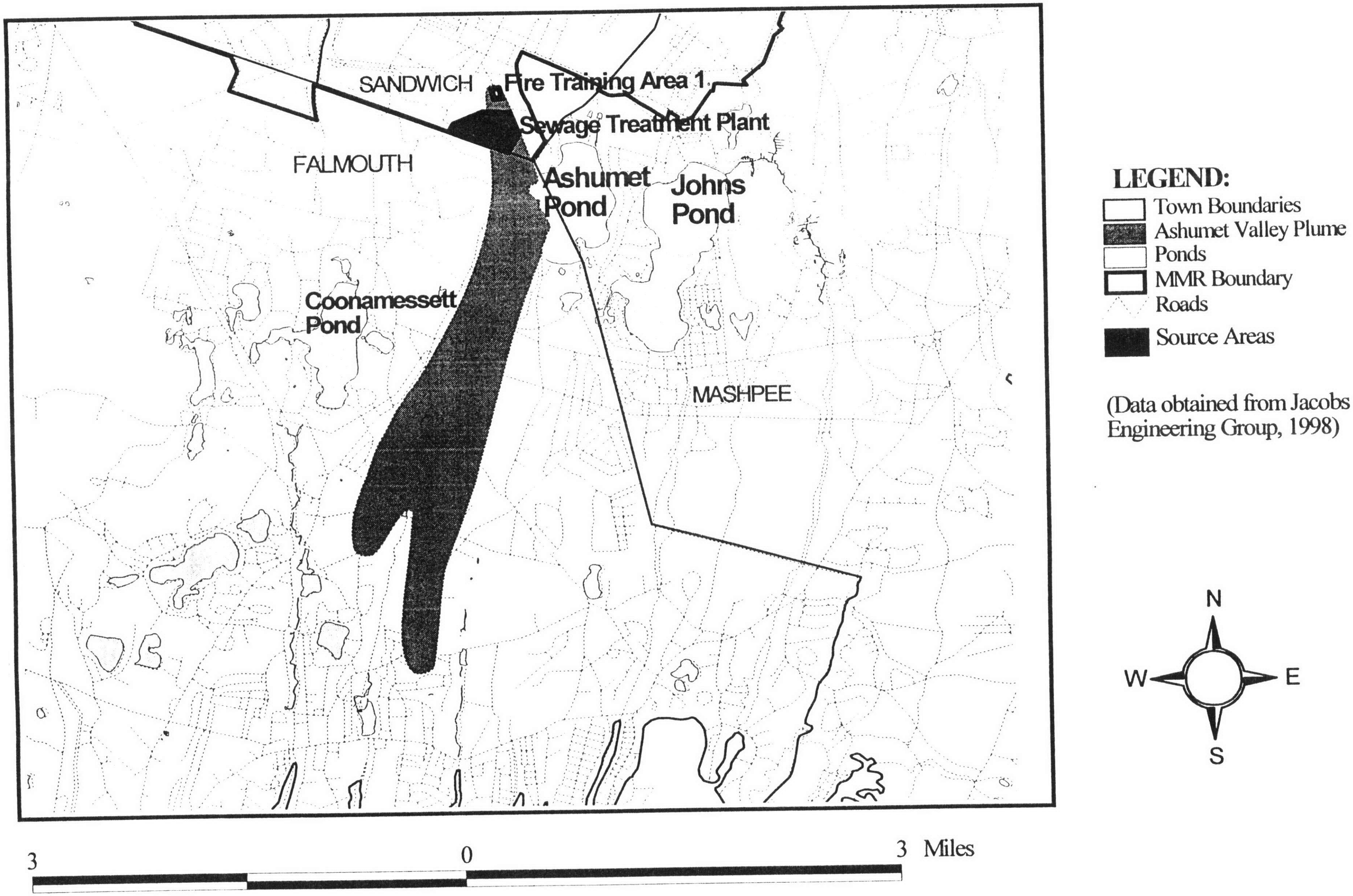


Figure 2-9: Location and extent of the Ashumet Valley ground-water plume, MMR, Cape Cod, MA

The capital cost of the ETR system is estimated to be $43 million dollars, and the operation and maintenance cost is projected to be approximately $3 million dollars per year. Total life-cycle cost, including capital cost, based on a 20-year design life is $98 million dollars (MMRIRP, 1997f).

2.7 Chemical Spill 4

Figure 2-10 illustrates the current extent and location of Chemical Spill 4 (CS-4) ground-water plume. It is 11,000 feet long, 800 feet wide, and approximately 50 feet thick (Khachikian *et al.*, 1996).

Table 2-4 lists the major contaminants detected at CS-4. According to the table, the average concentrations of TCE and PCE exceeded the MCL (Khachikian *et al.*, 1996).

Table 2-4: Chemical composition of ground-water plume CS-4.

Contaminant	Maximum Concentration[1] (μg/L)	Average Concentration[1] (μg/L)	MCL[2] (μg/L)
TCE	62	18	5
PCE	32	9.1	5
1,2-DCE	26	1.1	5
1,1,2,2-TeCA	24	6.8	0.4[3]

[1] (Khachikian *et al.*, 1996).
[2] (Jacobs, 1996a).
[3] No MCL listed, reported value represents Cleanup Level (Jacobs, 1996a).

The source area responsible for the CS-4 plume is illustrated in Figure 2-10. It was a former military-vehicle maintenance area for the U.S. Army between 1940 and 1946, and by the U.S. Air Force between 1955 and 1973 (CDM, 1997). During 1965-1983 it was operated as a storage yard. It is suspected that wastes such as oils, solvents, paint, antifreeze, and battery electrolytes were dumped in this area. Six 5,000-gallon underground storage tanks may have also contributed to the contamination resulting in CS-4 (CDM, 1997).

The CS-4 ground-water plume is currently being treated by an ETR system composed of 13 extraction wells. The wells are pumping at a total rate of approximately 164,000 gpd, and are aligned perpendicular to regional ground-water flow (CDM, 1997). The extracted water is pumped through a treatment system mainly comprised of granular activated carbon vessels. The treated water is then reinjected into the aquifer through an infiltration trench (CDM, 1997). The system was designed by ABB Environmental Services, and became operational in November 1993 (CDM, 1997). In March 1996, the AFCEE evaluated the performance of the ETR remediation system at CS-4 and concluded that the system was successfully capturing the contaminants in CS-4 (CDM, 1997).

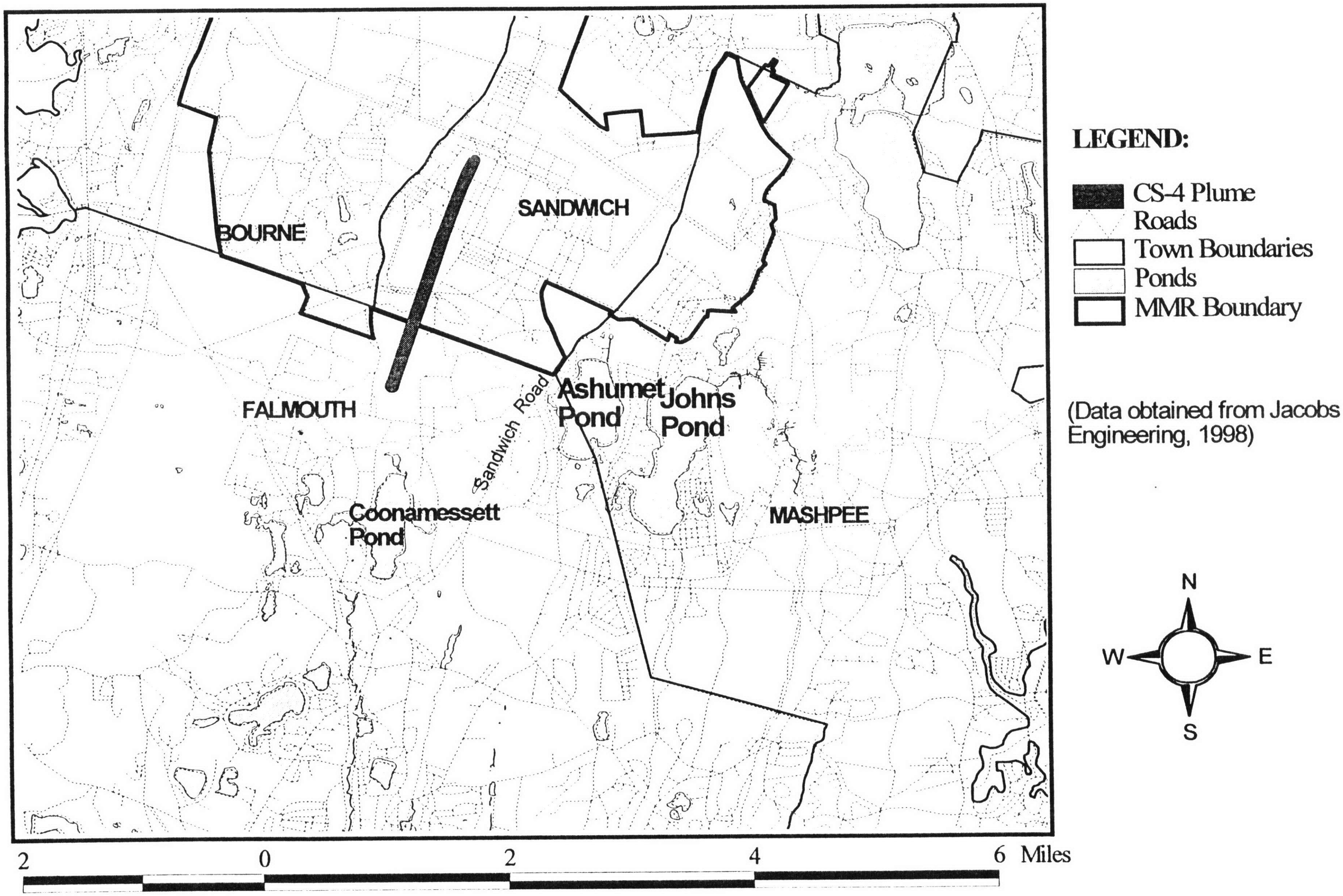


Figure 2-10: Location and extent of the CS-4 ground-water plume, MMR, Cape Cod, MA.

3. Geographical Information System (GIS)

GIS is a tool used to map, manage, and analyze geographic data. Its origin dates back to the early 1960s when Dr. Roger Tomlinson designed the first operational geographic information system to service the Canada Land Inventory (Allen *et al.,* 1990). However, the technical capability of combining both graphical and textual images in one application was not accomplished until the 1970s (Hutchinson and Daniel, 1997). The true turning point for GIS occurred in the early 1980s when the Environmental Systems Research Institute (ESRI) created ARC/INFO GIS for commercial use (Allen *et al.,* 1990). ESRI provided the industry with a standard solution for analyzing spatial problems by supplying software that integrated cartography, data management, and spatial analytical techniques. ESRI has continued to lead the industry into the computer age by developing a wide spectrum of applications, ranging from ArcView (a user-friendly, desktop application) to MapObjects/MapInfo (for the die-hard computer programmers).

The line of demarcation between GIS and automated mapping programs is evident when one compares their analysis capabilities. The true power of GIS lies in its ability to perform analyses on both its spatial and attribute data. GIS has four main analysis functions:

1. data retrieval, classification, and measurement
2. overlay
3. neighborhoods
4. network

The data retrieval, classification, and measurement functions allow for both spatial and attribute manipulation, however, the spatial data are not permanently altered. This capability allows the user to perform spatial queries, groupings, and modifications without changing the location of spatial elements. As a result, the user can quickly and easily identify patterns associated with the spatial data, or their attributes (Arnoff, 1989).

The overlay functions are typically used when comparing values from one or more coverages (data layers). GIS has the power to perform limited mathematical operations on overlapping layers. The type of coverage being analyzed, namely raster versus vector, dictates the output capability of the overlay functions. Because vector data is not continuous, the overlay functions have less potency and accuracy than with the raster images.

The neighborhood functions perform analyses on the surrounding area of a specified location. The user has the capability to specify the location, the region of interest, and the desired analysis to be performed on the selected data. The available analysis functions are derived from basic statistical functions, such as count, mean, max/min, standard deviation, sum, and variance (Arnoff, 1989).

Network functions are typically applied to vector coverages composed of lines. The network function traverses a line, and accumulates a value. As the function analyzes a group of lines, values are ranked representing relative distances. This method of analysis is particularly useful in defining direct routes between two specified locations, generating travel directions, and determining locations within a specified proximity.

3.1 GIS Data

GIS databases contain graphic and nongraphic information that describe spatial relationships or characteristics of a given area (Antenucci *et al.*, 1991). The nongraphic data describe the conditions or features illustrated by the graphic data. Graphic data are what comprise the data layers that compose a coverage. The graphic information is affiliated with a latitude, longitude, and elevation, derived from either Global Positioning Systems (GPS) or Remote Sensing.

Global Positioning Systems (GPS) are composed of a system of earth-orbiting satellites that transmit timed signals (Dana, 1998). The signals sent from the satellites are received by an electronic device, often hand-held. The device interprets the signal and outputs a direct measurement of position on the earth's surface in a standard coordinate system (typically latitude/longitude). Remote sensing is similar to GPS, however, remote sensing satellites process information about the earth's surface and atmosphere. The signals observed by these satellites depend on the satellite's location and part of electromagnetic spectrum sensed (Dana, 1998). The signals are transmitted to a receiving station, where they are transformed into digital images.

A coverage can represent a series of data layers that combine to depict a detailed map, or it may simply represent a single data layer. The data layer(s) that comprise a coverage may be classified as a point, line, or a polygon. A point coverage is a spatial representation of a zero-dimensional object that is defined by its geographic location within a coordinate system. A line coverage is a one-dimensional object that connects a number of geo-referenced points, and a polygon coverage is a two-dimensional object representing an area that is continuous and delineated by a geo-referenced line (Antenucci *et al.,* 1991).

Coverages can be stored as vector or raster images. A vector image uses a collection of points and lines to create a two-dimensional representation of an area. A raster image uses a matrix of cells or pixels to represent a surface. Vector images rely on an x,y coordinate system to locate the data, whereas, raster images store the information in a matrix of cells, with the spatial position implicitly defined by the order of the cells.

3.2 Coordinate Systems

There are a number of coordinate systems that can be used to reference geographic data. The most familiar coordinate system among users is the Cartesian system. This system represents coordinates based on right angles, and is often used in analytical geometry (Dana, 1997a). There are two other coordinate systems employed with GIS software packages. The Plane Coordinate System is a two-dimensional coordinate system that is defined with respect to a single plane. Three-Dimensional Coordinate Systems are defined with respect to two orthogonal planes.

3.2.1 Latitude/Longitude System

The most common geographic coordinate system is the latitude/longitude system. The reference plane for latitude coordinates is the equator and for longitudinal coordinates is the prime meridian (Figure 3-1) (Dana, 1997a). Figure 3-2 illustrates the methodology for defining latitudinal and longitudinal coordinates. The definition of latitude for a point is defined by the angular degree distance along a meridian in relation to the equatorial plane. The definition of longitude for a point is defined by the angular degree distance between a plane passing through the point and a reference plane; both planes must be tangent to the equatorial plane (Dana, 1997a).

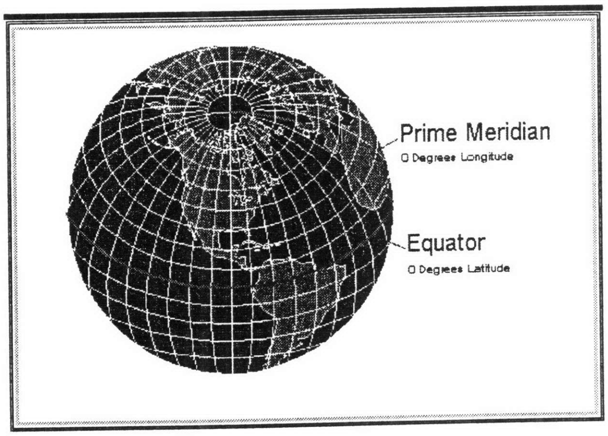


Figure 3-1: Reference planes for latitude and longitude coordinate systems (Dana, 1997b).

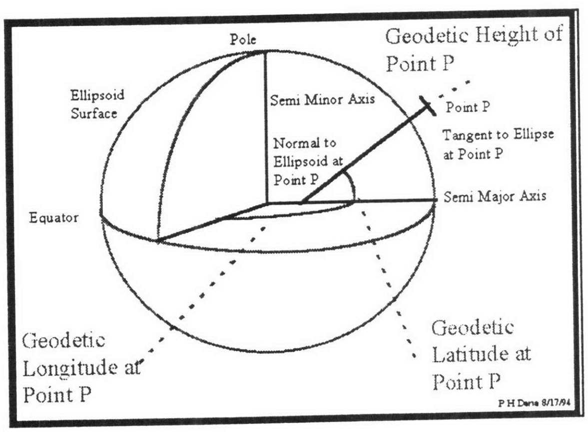


Figure 3-2: Definition of latitude and longitude (Dana, 1997b).

3.2.2 Universal Transverse Mercator (UTM)

The Universal Transverse Mercator (UTM) coordinate system represents two-dimensional, horizontal positions on the earth's surface in meters. Figure 3-3 illustrates the UTM zones defined for the world. Each zone has its own central meridian. A point is located within the zone by defining its distance eastward from the central meridian and northward from the equator.

All of the eastings have a positive value because the central meridian has a false easting of 500 km, and the northing value is indicative of the hemisphere. The equator has a northing of 0 for the northern hemisphere and has a false northing of 10,000 km for the southern hemisphere (Dana, 1997a).

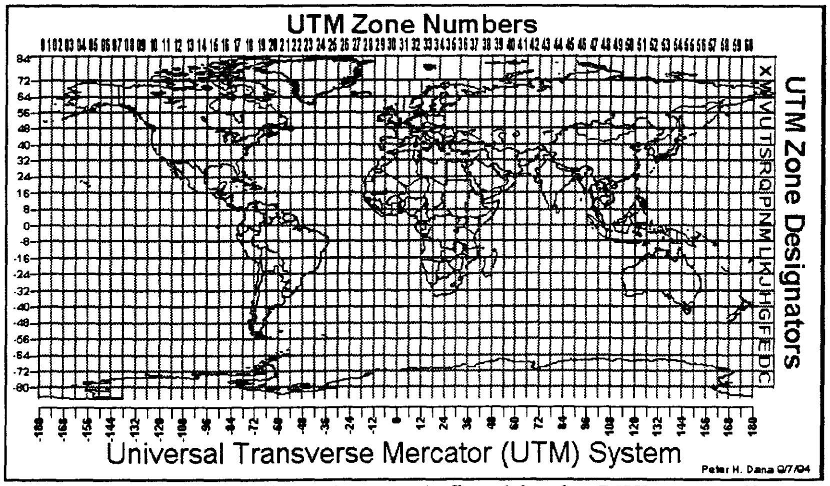


Figure 3-3: Zone delineation as defined in the UTM coordinate system (Dana, 1997b).

3.2.3 State Plane Coordinates (SPC)

The State Plane Coordinate system is used to measure geographic locations on a regional scale. These coordinate systems were created to define local coordinates relative to a national datum. The State Plane System 1927 was based on the North American 1927 datum (NAD27), measured in feet. The State Plane System 1983 has superseded the 1927 system, and is based on the North American Datum 1983 (NAD83) measured in meters. Each state has its own State Plane Coordinate System defined by the projection's parameters. The larger states must be split into zones, whereas the smaller states use a single plane zone. The geometry of the state dictates the type of projection used. The Lambert Conformal Conic Projection is used with states that have a greater east/west extent, such as Nebraska and North Carolina (Dana, 1997a). The Transverse Mercator projection is used with states that have a greater north/south extent, as with New Hampshire and Illinois (Dana, 1997a). The states that are split up into zones may have to incorporate both projections to accurately map the area. Florida requires both projections; the Transverse Mercator Projection is used for the east and west zones, whereas the Lambert Conformal Conic Projection is used with the northern zone (Dana, 1997a).

3.3 Reference Systems and Map Projections

Reference systems and map projections translate the area of interest from a Cartesian coordinate system to the surface of the earth (Dana, 1997b). Reference systems are defined by 'ellipsoidal earth' and 'complex gravity' models to delineate the shape of the earth. "Ellipsoidal earth models account for the minor flattening of the earth at the two poles. Due to this flattening, there is a twenty kilometer difference between the average spherical radius of the earth and the measured polar radius of the earth" (Dana, 1997b). Gravity models account for the influence of gravity on the sea level. Gravity anomalies may cause local variations in sea level. These variations cause additional irregularities in the earth's surface.

Map projections transform the spherical earth's surface onto a flat, two-dimensional plane (Dana, 1997b). Projecting a sphere onto a flat surface may result in the following distortions (Dana, 1997b):

- ***conformity***: scale of the map is the same in all directions. The lines of longitude (meridians) and lines of latitude (parallels) are perpendicular to each other. Shape is preserved locally.
- ***distance***: when a map portrays equal distances from the center to any point in the periphery it is equidistant.
- ***direction***: when the map's azimuths (angles from a point on a line to another point) are preserved in all directions, the direction is preserved.
- ***scale***: represents the distance on the map in relation to the distance on the earth.
- ***area***: the map is an equal-area map when the mapped areas have the same proportion as the areas on the surface of the earth.

Each map projection optimizes the view and extent while attempting to minimize the distortion, however, none of the map projections are devoid of all distortions. There are four main classes of map projections: (1) cylindrical projections, (2) pseudo-cylindrical projections, (3) conic projections, and (4) azimuthal projections (Dana, 1997b).

3.3.1 Cylindrical projection

Cylindrical projections represent the mathematical relationship of projecting a sphere onto a cylinder. Figure 3-4 illustrates the geometrical configuration involved in this mathematical concept. There are several types of cylindrical projections:

- **Cylindrical Equal-Area Projection** — equally spaced meridians, unequally spaced parallels. There are normal transverse and oblique cylindrical equal-area projections. The scale is true along the central meridian and along two lines equidistant from the central meridian.

- **Mercator Projection**— As illustrated in Figure 3-5 the parallels and meridians intersect each other at 90° angles. The scale becomes distorted as one moves away from the equator, its central line. It is conformal, but not an equal-area projection, so land masses near the poles are significantly exaggerated (Arlinghaus, 1993). This projection is particularly favorable for navigation purposes because the straight lines represent constant azimuth (Dana, 1997b).

- **Transverse Mercator** — similar to the mercator projection except it is developed from projecting a sphere onto a cylinder tangent to the central meridian. The center line passes through the north and south pole. The area on either side of the center line maintains true shape, but as one moves to the extreme east or west, the shape becomes distorted (Dana, 1997b). As a result, it is commonly used to map areas with greater north/south extents. It is a conformal projection and is the base for the UTM coordinate system (Arlinghaus, 1993).

- **Universal Transverse Mercator (UTM)** — a map projection and a coordinate system that categorizes the surface of the earth by 60 north/south zones (Dana, 1997b). Each zone is mapped with a transverse mercator projection and the central meridian is defined every 6 degrees, within the center of the zone.

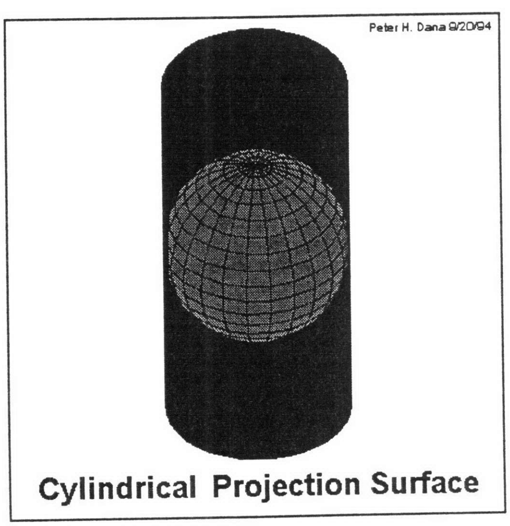


Figure 3-4: Geometric relationship defining the cylindrical projection (Dana, 1997b).

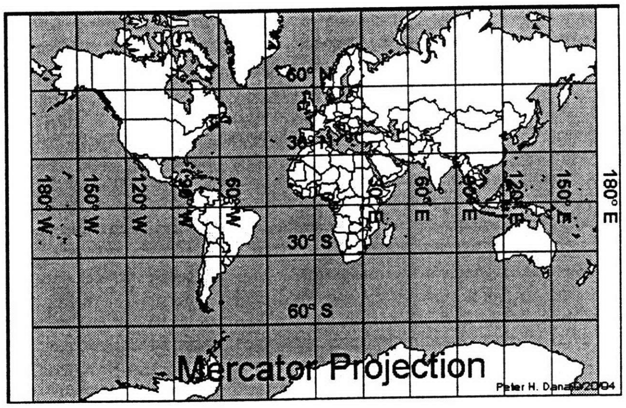


Figure 3-5: Mercator Projection illustrating the major continents in the world (Dana, 1997b).

3.3.2 Pseudo-cylindrical Projections

Pseudo-cylindrical projections are mathematically similar to cylindrical projections. They use the same geometric transformation of a sphere onto a cylinder, but the meridians in a pseudo-cylindrical projection are curved (Dana, 1997b). The benefit of using such a projection is that it minimizes the area and angular distortions prevalent with conical projections (Arlinghaus, 1993). There are several pseudo-cylindrical projections:

- **Mollweide Projection**— As illustrated in Figure 3-6, the central meridian is straight, but the 90th meridians are circular arcs. Shape and scale are maintained near the central meridian, but become distorted away from the central line. This is typically used for world-maps because this projection maintains equal-area (Dana, 1997b).

- **Eckert IV Equal-Area Projection**— As illustrated in Figure 3-7 the central meridian is straight, the 180th meridians are semi-circles, and the other meridians are elliptical. Distortion of shape increases away from the central meridian (Dana, 1997b). Due to the equal-area representation, this projection is commonly used with world maps.

- **Eckert VI Equal-Area Projection** — As illustrated in Figure 3-8, the central meridian is tangent to all parallels and the remaining meridians are sinusoidal curves. This equal-area projection experiences significant shape distortion as one moves towards the poles (Dana, 1997b).

• **Sinusoidal Equal-Area Projection** — As illustrated in Figure 3-9, straight parallels tangent to the central meridian and the remaining meridians are sinusoidal curves. The scale is only true at the central meridian. This map projection is typically used with areas that have large north/south extents (Dana, 1997b).

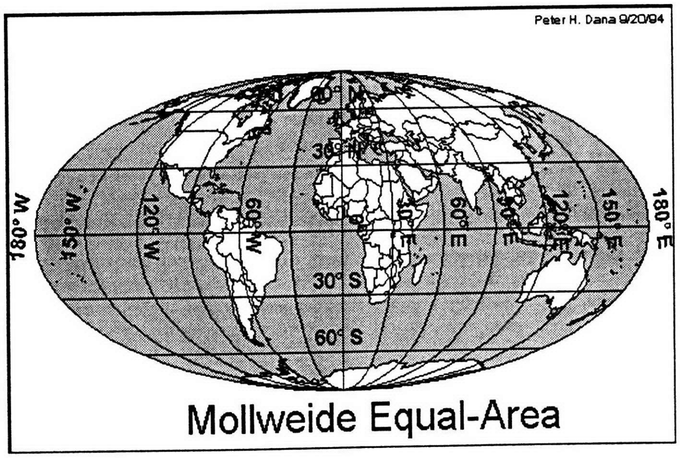


Figure 3-6: Global extent using an Mollweide Equal-Area projection (Dana, 1997b).

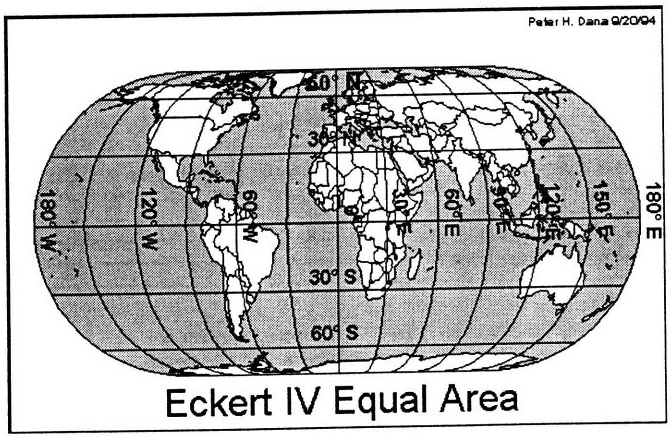


Figure 3-7: Global extent using an Eckert IV Equal-Area projection (Dana, 1997b).

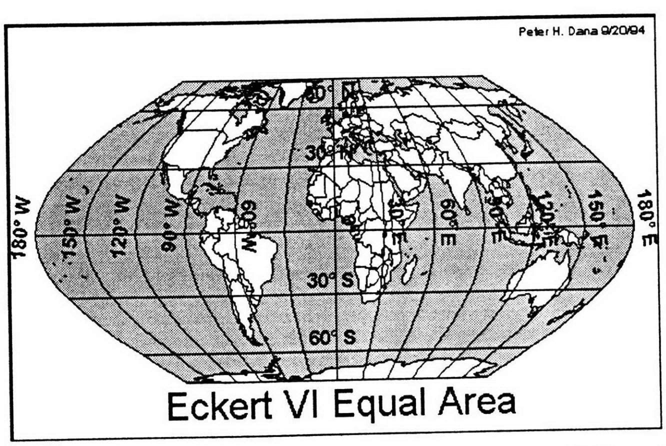


Figure 3-8: Global extent using an Eckert VI Equal-Area projection (Dana, 1997b).

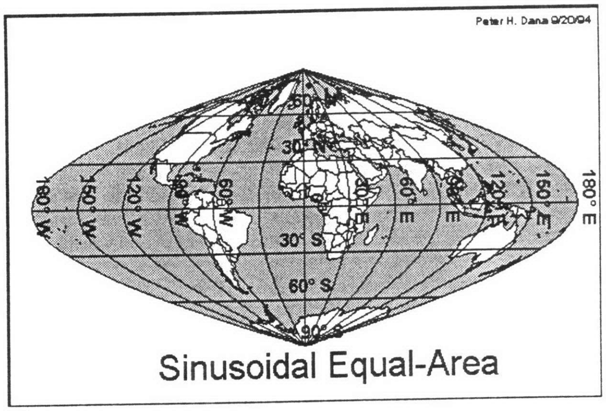


Figure 3-9: Global extent using a Sinusoidal Equal-Area projection (Dana, 1997b).

3.3.3 Conical Projections

Conical projections represent the mathematical transformation of projecting a sphere onto a cone from a point at the center of the sphere (Arlinghaus, 1993). Figure 3-10 illustrates the geometric relationship involved in this transformation. There are two main conical projections typically used:

- **Albers Equal-Area Conic Projection** — Figure 3-11 illustrates an equal-area projection that is defined by two standard parallels. There is no angular distortion along these two parallels, therefore, this projection is useful with areas that have a greater east/west extent than north/south extent (Dana, 1997b). The farther one moves from the standard parallels, the more severe the distortion (Arlinghaus, 1993).

- **Lambert Conformal Conic Projection** —Figure 3-12 illustrates two standard parallels that are equally spaced and at right angles to the straight meridians (Arlinghaus, 1993). This projection causes symmetrical distortion about the center meridian, therefore, it is typically used with "continent-scale" maps (Arlinghaus, 1993).

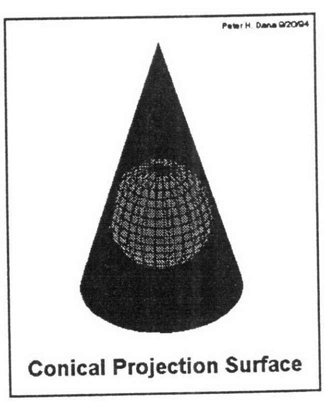


Figure 3-10: Geometric relationship defining the transformation of conical projection (Dana, 1997b).

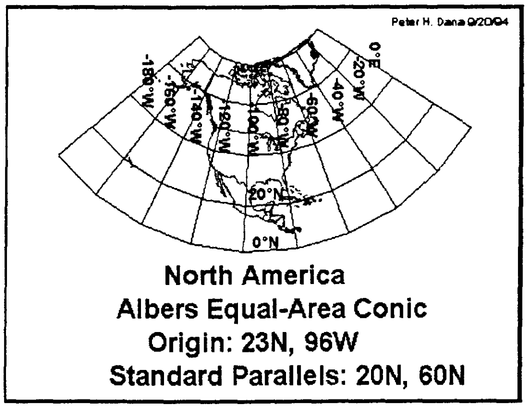


Figure 3-11: Albers Equal-Area Conic Projection for North America (Dana, 1997b).

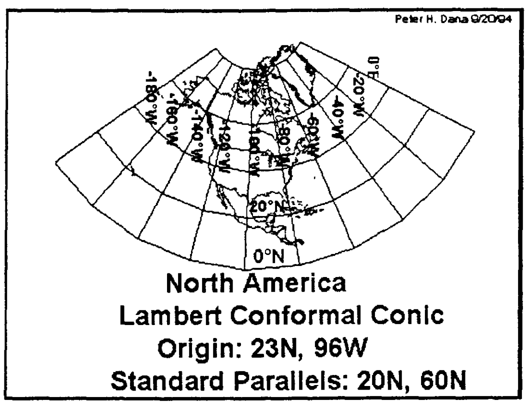


Figure 3-12: Lambert Conformal Conic Projection for North America (Dana, 1997b).

3.3.4 Azimuthal Projections

Figure 3-13 illustrates the geometric relationship for azimuthal projections. As the figure demonstrates, azimuthal projections represent the mathematical transformation of projecting a sphere onto a plane tangent to any point on the sphere (Arlinghaus, 1993). The horizontal direction measured from the center of the projection is always true because there is no distortion at the map center. There are several types of azimuth projections:

- **Azimuthal Equidistant Projection** — As illustrated in Figure 3-14, the distances measured outward from the center along azimuths are accurate. Due to the high accuracy associated with distance measurements, this type of projection is typically used to illustrate air-route distances (Dana, 1997b).

- **Lambert Azimuthal Equal-Area Projection** — As illustrated in Figure 3-15, the central meridian is straight, but the remaining meridians are curved. This projection sacrifices shape for maintaining equal-area between the parallels (Arlinghaus, 1993).

- **Orthographic Projection** — (illustrated in Figure 3-16) the center of the projection is at infinity, which helps maintain sphericity. This is useful for mapping hemisphere extents, but does not accurately maintain shape. It is a more common projection with visual displays not less concerned about accuracy (Arlinghaus, 1993).

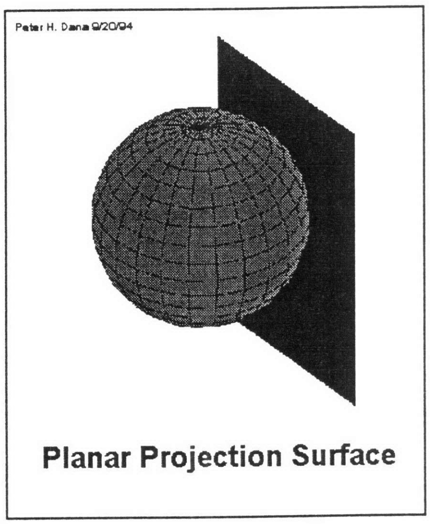


Figure 3-13: Geometric relationship for transformation of azimuthal projection (Dana, 1997b).

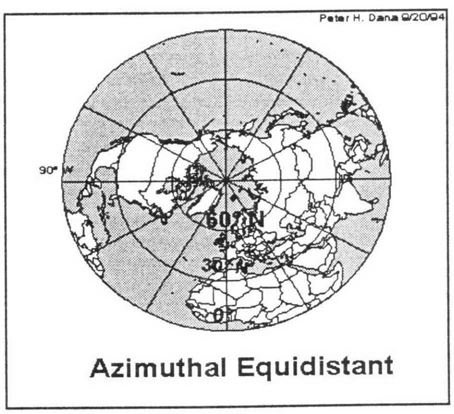


Figure 3-14: Azimuthal Equidistant Projection centered at the North Pole (Dana, 1997b).

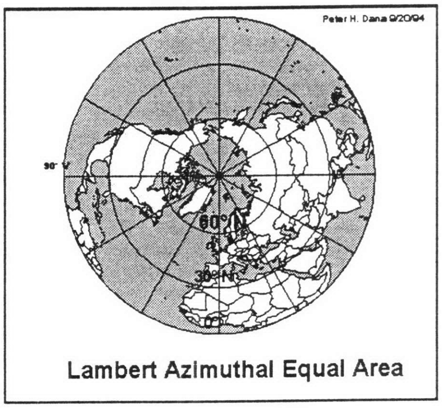


Figure 3-15: Lambert Azimuthal Equal-Area Projection centered at the North Pole (Dana, 1997b).

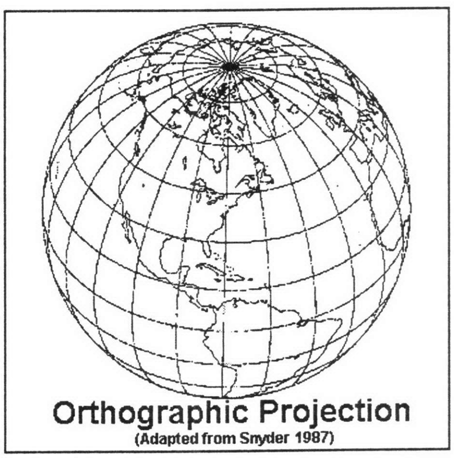


Figure 3-16: Global extent using the Orthographic Projection (Dana, 1997b).

4. Capture Curves

The MMR has traditionally employed pump-and-treat systems as a method of remediation. Pump-and-treat systems, as described in chapter 2, are typically composed of an extraction well(s), an injection well(s), and an above-ground treatment system. They are used to both extract contaminants from the subsurface and to impose hydraulic control on the region of contamination. In order to maximize hydraulic control and ensure plume containment, the aquifer properties and pumping scenarios must be analyzed with respect to the capture zone.

The area surrounding a well that supplies water to the well defines a capture zone (Domenico and Schwartz, 1990). All water that falls within the capture zone will be extracted by the pumping well. Water parcels that fall outside the capture zone are not entrained by the well, and continue to migrate in the direction of the regional ground-water flow. The capture zone is delineated by a streamline typically referred to as the capture curve.

4.1 Dimensions

The dimensions of the capture curve are dependent upon both the magnitude of ground-water extracted and the uniform regional flow (Domenico and Schwartz, 1990). Javendel and Tsang (1986) defined the following equation for a capture curve in a homogeneous, isotropic, infinite aquifer:

$$y = \pm\frac{W}{2} - D\tan^{-1}\left(\frac{y}{x}\right) \qquad (1)$$

where W represents the maximum width of the capture curve, D represents the distance from the well to the stagnation point, and y is the width of the capture curve at a distance x from the well. Figure 4-1 illustrates the general shape of a capture curve defined by the aforementioned equation. According to equation one, the streamline defining the capture zone extends infinitely upgradient. There is no upgradient boundary because all water parcels within the width of the capture curve will naturally flow downgradient, towards the well.

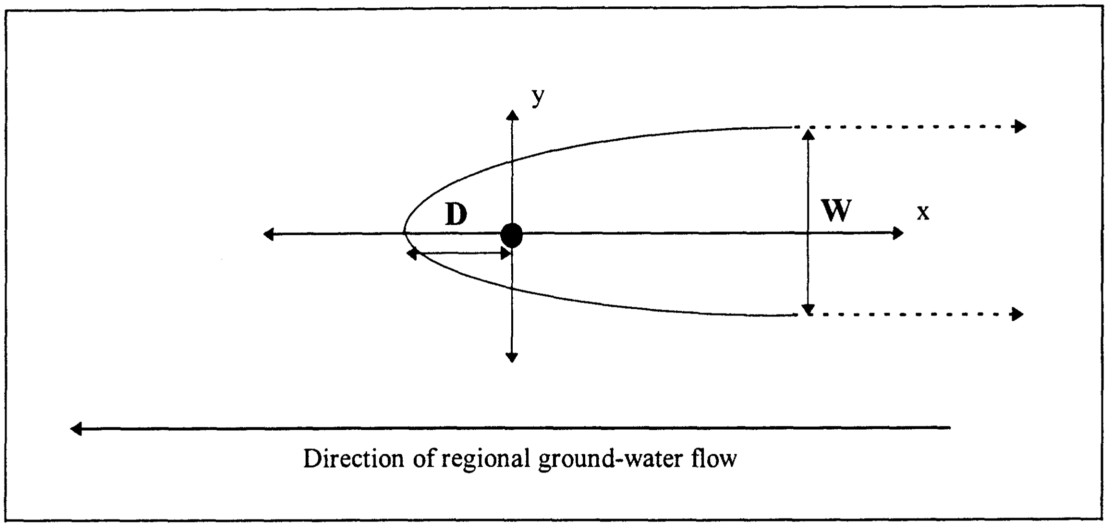


Figure 4-1: Parabolic capture curve for a single well.

4.2 Stagnation Point

The variable D in Figure 4-1 represents the distance from the well to the downgradient point of stagnation. A water parcel at the stagnation point has a velocity of zero, and therefore is stagnant. At this point, the radial specific discharge (q_r) is equal to the uniform specific discharge (q_u). The variable D is calculated by superimposing the specific discharge of the uniform regional ground-water flow with the radial specific discharge:

$$D = \frac{Q_p}{2\pi * T * I}$$

where the derivation is as follows:

$$q_r = \frac{Q_p}{2\pi * r * B} \qquad (2)$$

q_r = radial specific discharge
r = radial distance from the well
B = aquifer thickness
Q_p = pumping rate of extraction well

$$q_u = K * I \qquad (3)$$

q_u = uniform specific discharge
K = hydraulic conductivity

I = hydraulic gradient

The principle of superposition, in conjunction with the definition of stagnation, (superimposed equal and opposite velocities sum to zero at the stagnation point) allow the uniform specific discharge to be equated with the radial specific discharge:

$$q_u = q_r \tag{4}$$

Equation 4 can be restated as:

$$K*I = \frac{Q_p}{2\pi*r*B}$$

The aquifer transmissivity, T, is defined as:

$$T = K*B \tag{5}$$

Substituting for T, and rearranging to solve for r yields:

$$r = \frac{Q_p}{2\pi*T*I} \tag{6}$$

At the stagnation point, r is equal to D, the distance to stagnation:

$$\therefore \; D = \frac{Q_p}{2\pi*T*I} \tag{7}$$

4.3 Maximum Width

The maximum width (W) of the capture zone, as illustrated in Figure 4-1, is attained at a significant distance upgradient from the well, where the regional ground-water flow is not influenced by the pumping well, and is therefore uniform. As a result, the width (W) can be quantified by equating the uniform, regional ground-water flowrate with the pumping rate:

$$W = \frac{Q_p}{T*I}$$

where the derivation is as follows:

$$Q_u = T*I*W \qquad (8)$$

Q_u = uniform, regional ground-water flowrate
T = transmissivity of the aquifer
I = hydraulic gradient
W = width

Based on the equation of continuity:

$$Q_{\text{Total into the well}} = Q_{\text{Total out of well}} \qquad (9)$$

Restating equation 9:

$$Q_u = Q_p \qquad (10)$$

Substituting equation 7 into equation 9 yields:

$$T*I*W = Q_p \qquad (11)$$

Rearranging and solving for W:

$$\therefore \; W = \frac{Q_p}{T*I} \qquad (12)$$

According to equations 7 and 12, the aquifer characteristics and the pumping rate of the extraction well dictate the dimension of the capture curve.

5. Capture Curve Approximation (CCA) Program

As discussed in chapter 2, the MMRIRP regularly approves pump-and-treat systems to contain migrating plumes at the MMR. These systems are difficult to design because there are a number of plausible pumping scenarios that can be implemented at a site. Before the design engineer can begin to optimize a remediation solution, he/she must first quantify the capture potential of various pumping scenarios. Due to the infinite number of plausible pumping schemes, the task of quantifying the capture potential for each system is time-consuming, making it a perfect candidate for software automation.

The difficulty in quantifying the effectiveness of various pumping schemes is attributed to the lack of user-friendly applications that accurately represent the current conditions of a site. However, GIS has the potential to alleviate these problems. ESRI has developed GIS products that have the strength to perform complex analyses without compromising the degree of user-friendliness. The geo-referenced information stored in a GIS database can be updated or appended daily, providing the user with the most current and exhaustive site information.

The objective of this project is to develop the Capture Curve Approximation (CCA) Program, an interactive, user-friendly, GIS application that approximates the capture potential of a user-defined extraction well. To accomplish this objective, two major tasks were requisite: (1) create an algorithm to approximate the capture curve, and (2) create the graphical interface between the user and the CCA algorithm.

5.1 Rectangular Approximation

As discussed in chapter 4, a capture curve delineates the zone of capture for a given well, pumping at a given rate, in an aquifer with certain hydraulic characteristics. Although this curve is typically parabolic, it can be approximated as a rectangle. Figure 5-1 illustrates the difference between a rectangular approximation of the zone of capture versus the theoretical capture curve. Although the rectangular approximation slightly overestimates the capture zone area, this error is considered to be minor for the scale at which the curves are generated.

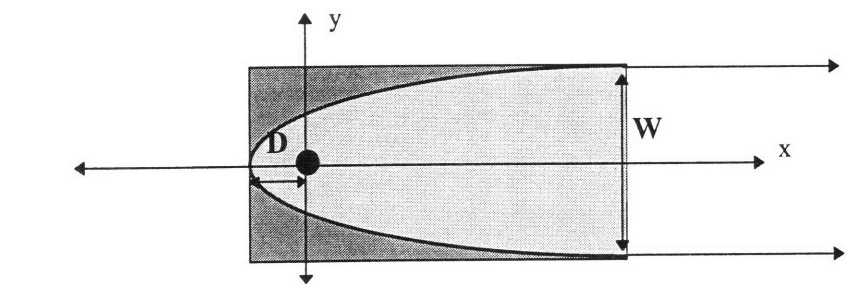


Figure 5-1: Disparity between rectangular approximation and theoretical zone of capture.

Although the capture curve extends infinitely upgradient, for the purposes of the CCA program, an upgradient boundary had to be defined. The scale at which the user will be viewing the ground-water plumes did not warrant an infinite, or near infinite endpoint. Therefore the end-point used in the CCA program had to be selected by optimizing aesthetics with capture-curve theory. This optimization was reached using a length calculated by equation 13:

$$x = \frac{\frac{0.55W}{2}}{\tan\left(\frac{\frac{0.55W}{2} - \frac{W}{2}}{-D}\right)} \qquad (13)$$

Equation 13 is developed by rearranging equation 12 to calculate the capture curve length (x) given a width (y) equal to 55% of the maximum width (W). This width (y = .55W/2) is selected because it provides an adequate description of the capture zone without compromising the scale of the view.

5.2 Coding

All of the scripts used in the CCA program are available in Appendix A. The scripts (programs) were written in Avenue, an object-oriented computer programming language specific only to ArcView. Object-oriented languages rely on objects, classes, and requests. An object is the entity that represents a component in Arcview. It can range from a project specific component, such as a view or a theme, to a basic element in a view, such as a point or polygon. The objects in Arcview are classified by a hierarchical class system. The class represents the characteristics common to all objects that are grouped in that class. For example, the shape class has six subclasses: circle, line multipoint, oval, point, and rect. The requests enable the user to create, control, or get information about objects, and each class has its own defined set of requests (ESRI, 1996). The request defines what an instance of the class will do and the method by which it is accomplished. An example of a request is:

```
thename = theView.Getname
```

The "Getname" request returns the name of the object "theView" to the variable "thename" (ESRI, 1996).

5.3 Methodology

Figure 5-2 illustrates the major flow of events completed in the CCA algorithm. As illustrated in the figure, the first step in the algorithm was to acquire the user-defined information. In the beginning of the program, the user is prompted to identify the position of the extraction well by clicking on the desired location and is then prompted to enter the preferred pumping rate, and the percent thickness of the aquifer the capture zone should span. This task required Avenue scripting to create message boxes to communicate with the user, and to translate the information from the user back to the program.

The algorithm then calculates the dimensions of the rectangular capture curve, relying on data from three sources. The first data source supplies the user-defined pumping rate. The second source supplies the value of transmissivity (T) globally assigned to Cape Cod. The transmissivity value used in the algorithm is 21,000 ft^2/d. This value was generated using a weighted average of the transmissivity values obtained for the four towns abutting the MMR (Bourne, Sandwich, Falmouth, and Mashpee). The town transmissivity values were also generated from a weighted average of transmissivity layers developed for a ground-water flow model for Cape Cod, conducted by the United States Geological Survey (Guswa and LeBlanc, 1985). Appendix B illustrates the procedure used to generate the regional transmissivity.

The regional transmissivity represents an aquifer with a thickness of 100%. If used in the analysis, the generated capture curve would imply 100% capture over the entire depth of the aquifer, however, the user may not wish to capture 100% of the aquifer. Therefore, to get a more accurate approximation, the user-defined percent thickness is applied to the regional transmissivity to define a capture zone that spans only the user-desired aquifer thickness.

The third data source supplies the hydraulic gradient for the plume, or portion of the plume, closest to the user-defined well. The magnitude and direction (with respect to the x-axis) of the hydraulic gradient is quantified for each plume, and some of the larger plumes have multiple hydraulic gradients, depending upon the location within the plume. Appendix C defines the approach used to estimate the magnitude and direction of the hydraulic gradient. Upon retrieving the necessary data from the aforementioned data sources, the algorithm calculates the dimension of the rectangular capture curves.

Inherent in the rectangular capture curve approximation is the assumption that the well is located at the origin of a Cartesian coordinate system, and x-axis of the capture curve is parallel to the direction of the regional ground-water flow. In order to account for this assumption, the dimensions of the rectangular capture curve needed to be translated onto a latitude/longitude coordinate system and rotated parallel to the hydraulic gradient before it could be plotted. The vector describing the translation is obtained from the user-defined information, because the coordinates of the well are defined with respect to the latitude/longitude coordinate system. The angle of rotation is equal to the direction of the hydraulic gradient, already obtained in step two. The relationship of the original capture curve coordinate to the rotated coordinate is specified by the following equation:

$$\begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} x\cos\alpha - y\sin\alpha \\ x\sin\alpha + y\cos\alpha \end{pmatrix} = \begin{pmatrix} x' \\ y' \end{pmatrix}$$

where x and y represent the original coordinates, α represents the angle of rotation, and x' and y' represent the new rotated coordinates (Bowyer and Woodwark, 1993).

After the dimensions of the capture curve are rotated and translated, the fourth and final step is completed. The rectangular capture curve is plotted on the main view, allowing the user to observe the spatial extent of the area of contribution, given the well location and pumping rate. The user has the capability of generating a capture curve for as many wells as desired, however, the program can only perform the calculation for one well at a time.

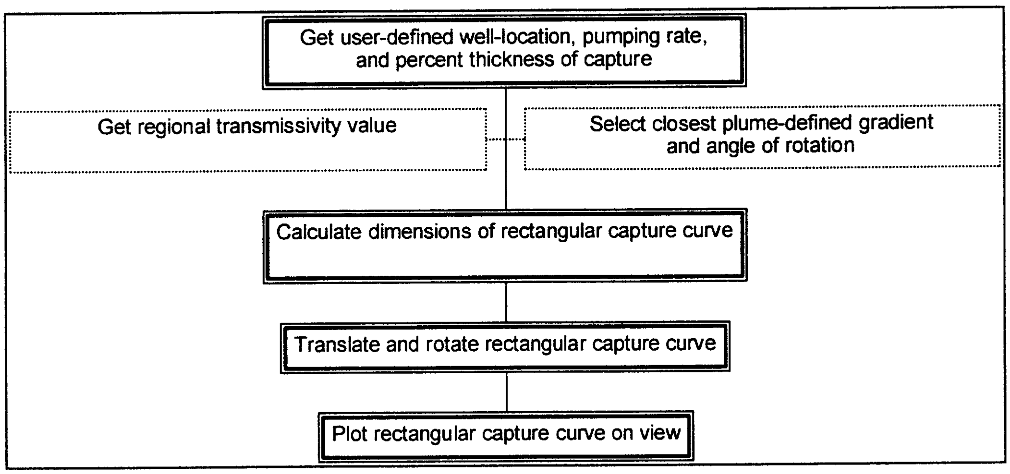


Figure 5-2: Progression of the major events in the CCA algorithm.

5.4 CCA Graphical Interface

The CCA program employs ArcView GIS 3.0a to serve as the graphical interface between the user and the CCA algorithm (ESRI, 1996). ArcView GIS 3.0a is an ESRI software package used for desktop mapping and geographic analysis and can be customized using the computer language Avenue (see section 5.2). ArcView's capability to display various spatial coverages at once, combined with the ability to customize the interface, makes it an ideal front-end software package for graphical data.

Jacobs Engineering Group Inc. supplied the majority of the coverages used in the graphical interface. The coverages were projected in Massachusetts State Plane Coordinate System with a NAD83 datum (see chapter 3).

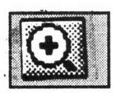
Figure 5-3 illustrates the screen images the user initially sees upon commencing the CCA program. After the user acknowledges the program's greeting (Figure 5-3), the view changes to the screen image illustrated in Figure 5-4. This screen illustrates the major ground-water plumes at the MMR with respect to their location on the Cape. Each feature (i.e., ground-water plume, MMR boundary, water body, etc.) is identified with a specific pattern/color and is defined in the table of contents to the immediate left of the view.

The view illustrated in Figure 5-4 is the main screen with which the user interacts, and he/she has several options as defined by the menus and tool buttons at the top of the screen:

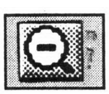
- Zoom-in, zoom-out, or zoom to a specific ground-water plume
- Install a well and generate the rectangular capture curve
- Create a map of the generated capture curve(s)

5.4.1 View Extent

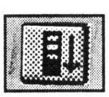
As evident by Figure 5-4, the scale of the main view is somewhat illegible and therefore, the user may wish to zoom to a particular region. The **Zoom** menu provides the user with the capability of zooming-in, zooming-out or zooming to a selected feature within the view. The following tool buttons can be used in lieu of the Zoom menu:



To zoom-in, click on the tool and drag a rectangle around the area of interest.

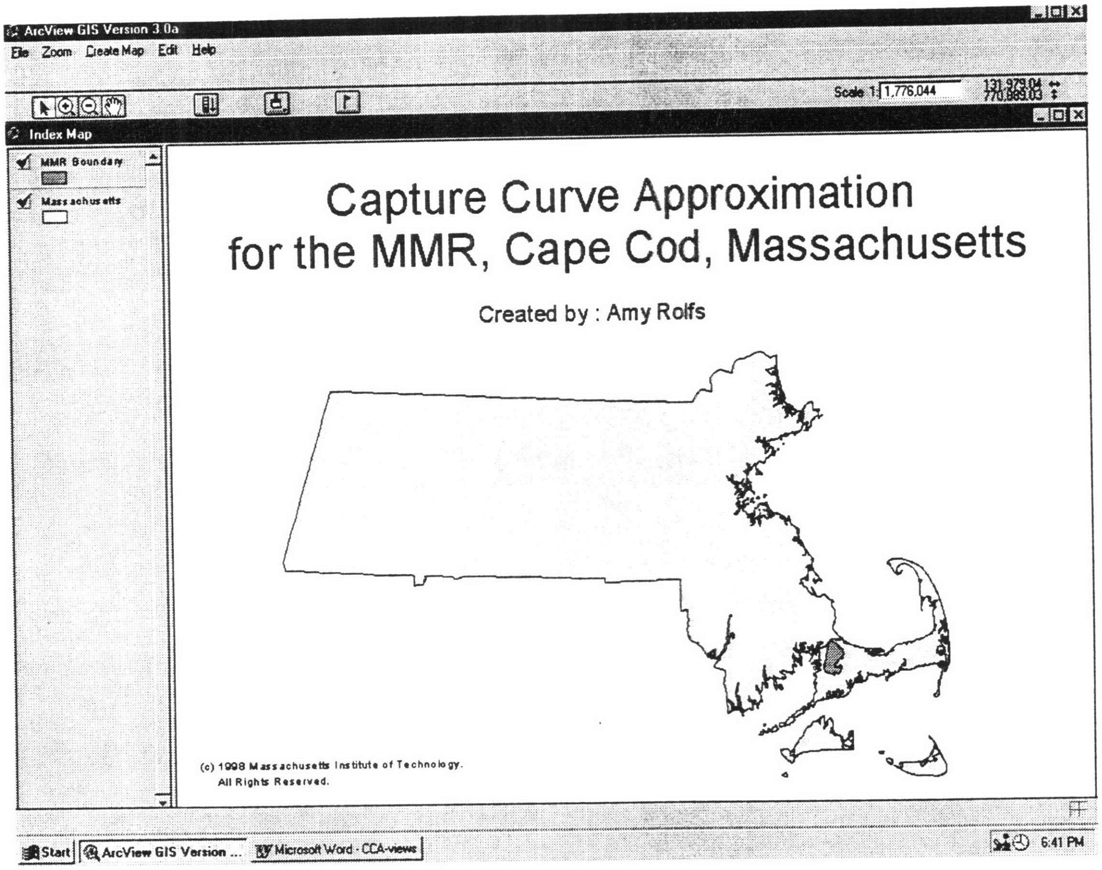


To zoom-out, click on the tool and drag a rectangle around the area of interest.



To zoom to the extent of a particular feature, click on the tool and in the pop-up menu select the desired feature to zoom to. Figure 5-5 illustrates the pop-up menu and the list of features available to zoom to.

To pan the view, click on the tool and then click and drag the view until the desired extent is visible.



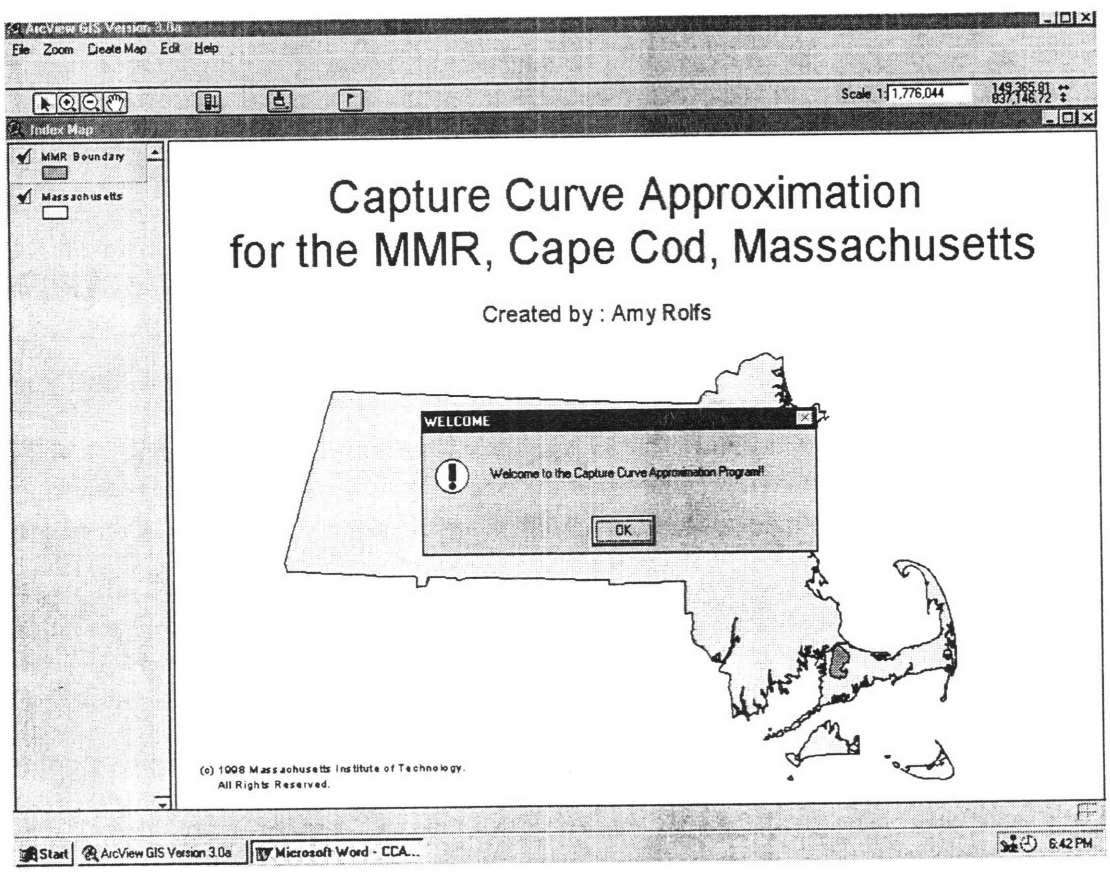


Figure 5-3: Introductory screens of the CCA program.

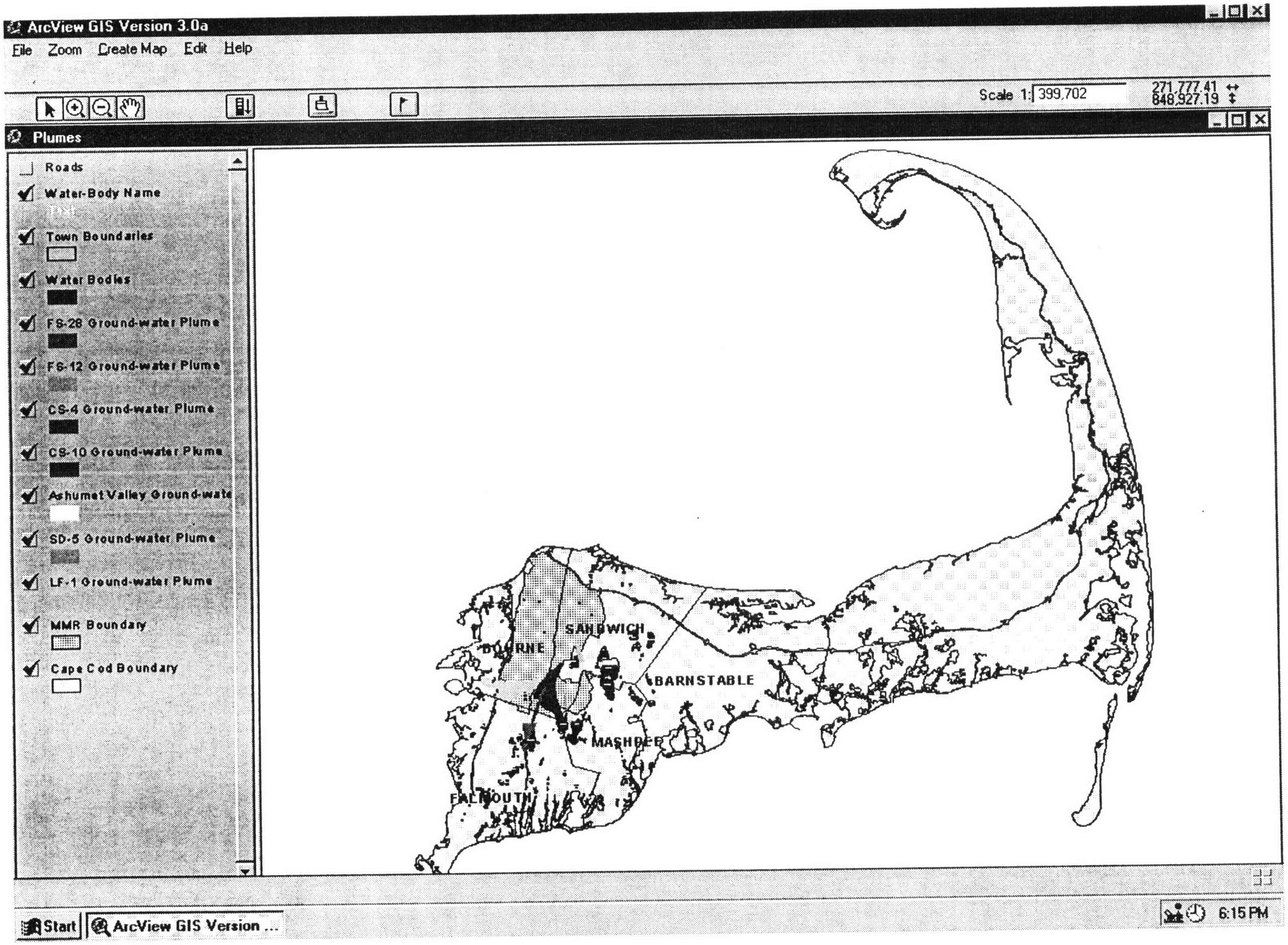


Figure 5-4: Main screen of the CCA program.

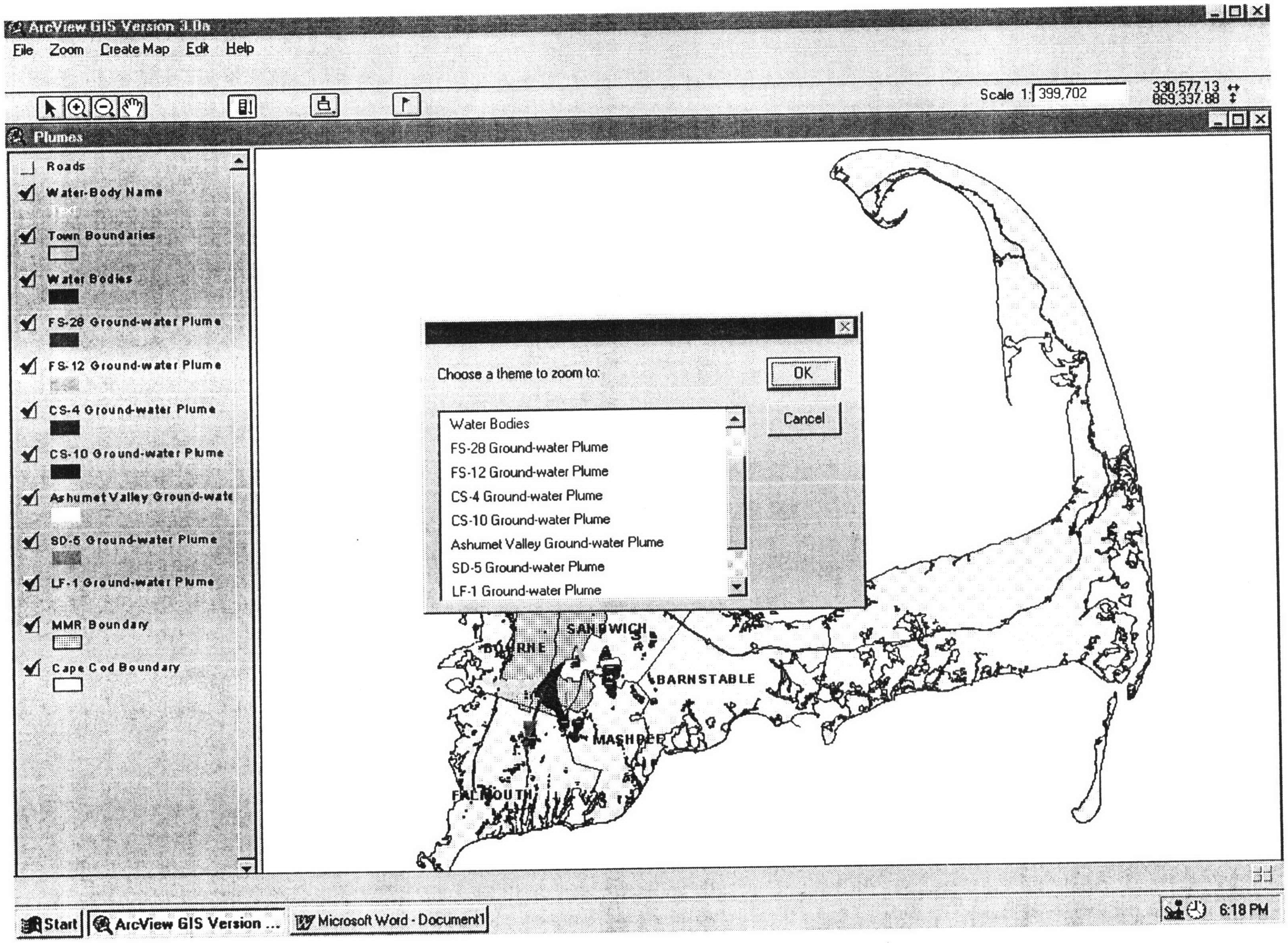


Figure 5-5: Screen image illustrating the “Zoom to Selected Feature” menu.

5.4.2 Install Well and Generate Capture Curve(s)

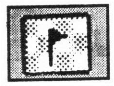
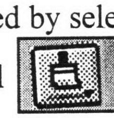
After the user is comfortable with the view extent, he/she can install a well anywhere within the view by clicking on the tool  and then clicking on the desired location. As soon as the user defines the well location, a menu pops-up on the display requesting the pumping rate, in gallons per minute, of the extraction well. Once the pumping rate is supplied another menu pops-up on the screen requesting the percent thickness of the aquifer captured by the well. Figure 5-6 illustrates these menus.

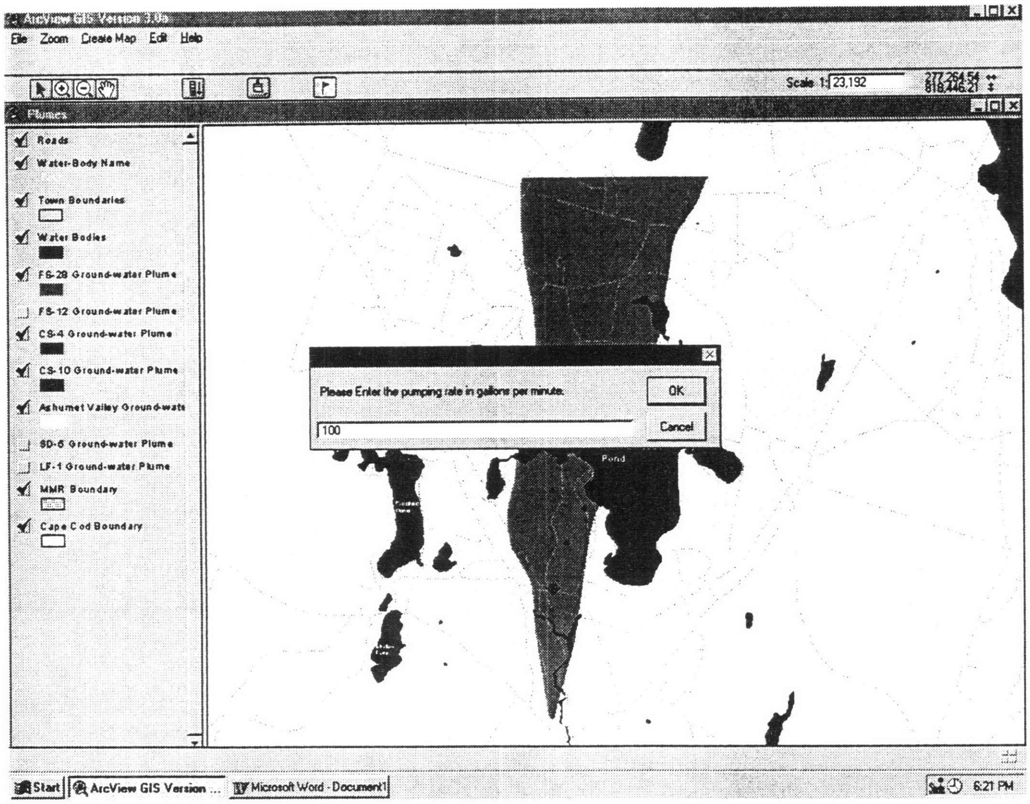
Figure 5-7 illustrates the screen image upon completion of the capture curve approximation. The figure depicts a capture curve corresponding to a pumping rate of 100 gallons per minute, capturing 50% of the aquifer depth. The new capture curve is also added to the table of contents, to the right of the view. The naming convention of this feature is Q100 / 50% T, where the Q100 represents the pumping rate, and 50%T represents the percent thickness the user previously specified.

The user may add as many wells as desired. If he/she wishes to remove a capture curve he/she can either permanently delete the capture curve using the "Delete Capture Curve" command under the **Edit** menu, or he/she can temporarily remove the capture curve from the screen by clicking of the check-mark next to the name of the capture curve in the table of contents (to the immediate left of the view). The user may also delete the well from the screen by clicking on the tool , clicking on the well, and then selecting the "Delete Graphics" command under the **Edit** menu.

5.4.3 Map Generation

At any point within the program the user can create a map illustrating the capture potential of his/her capture curves. This can be accomplished by selecting the "Create Map" command under the **Create Map** menu or by clicking on the tool .

After issuing the command to create a map, the user is prompted for a title for the map. Once the user specifies a title, the screen changes to the layout view. This screen is illustrated in Figure 5-8. As evident by the figure, this screen is slightly different than the main view. The menus



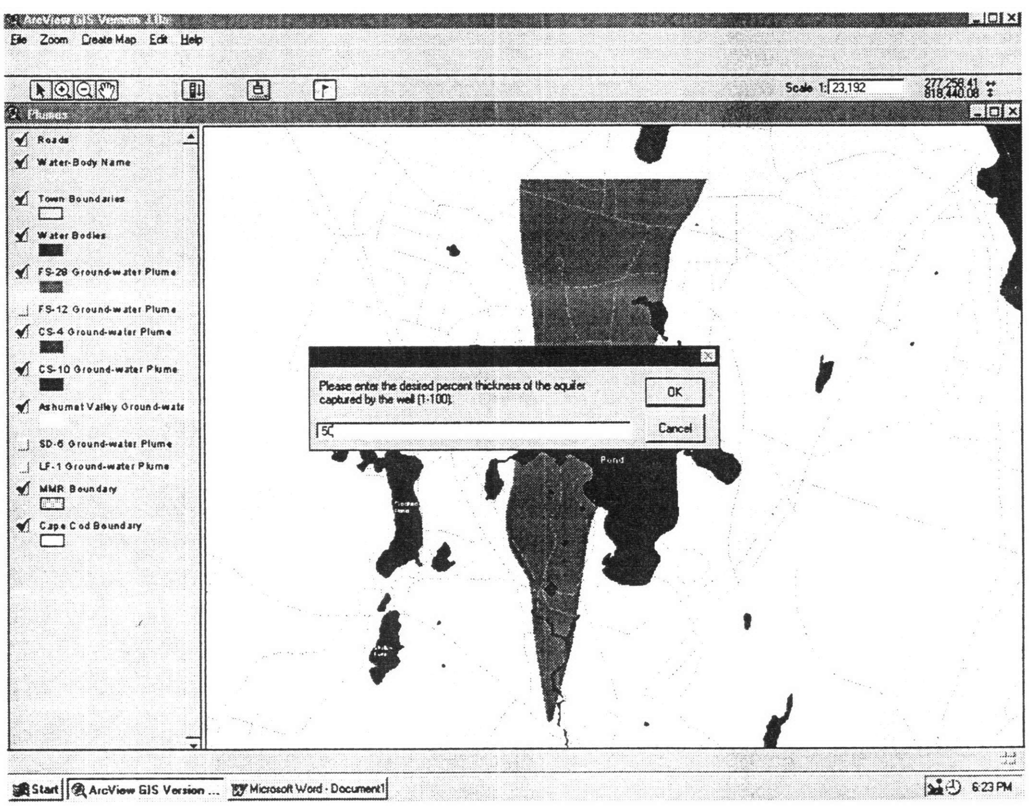


Figure 5-6: Progression of menus requesting information from the user prior to generating the capture curve.

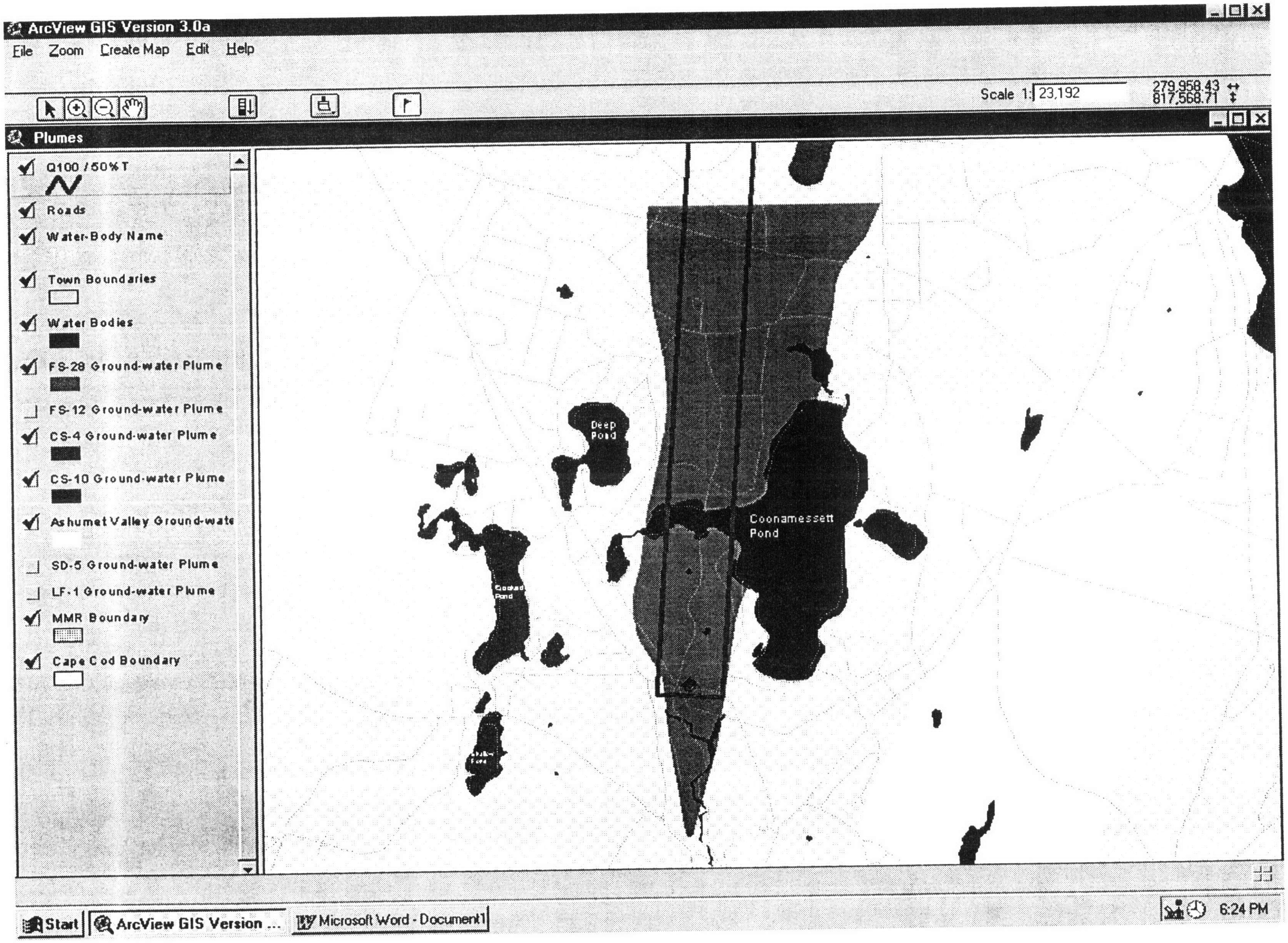


Figure 5-7: Screen image illustrating the approximated capture curve for an extraction well in ground-water plume FS-28 pumping at a rate of 100 gallons per minute, capturing 50% of the aquifer depth.

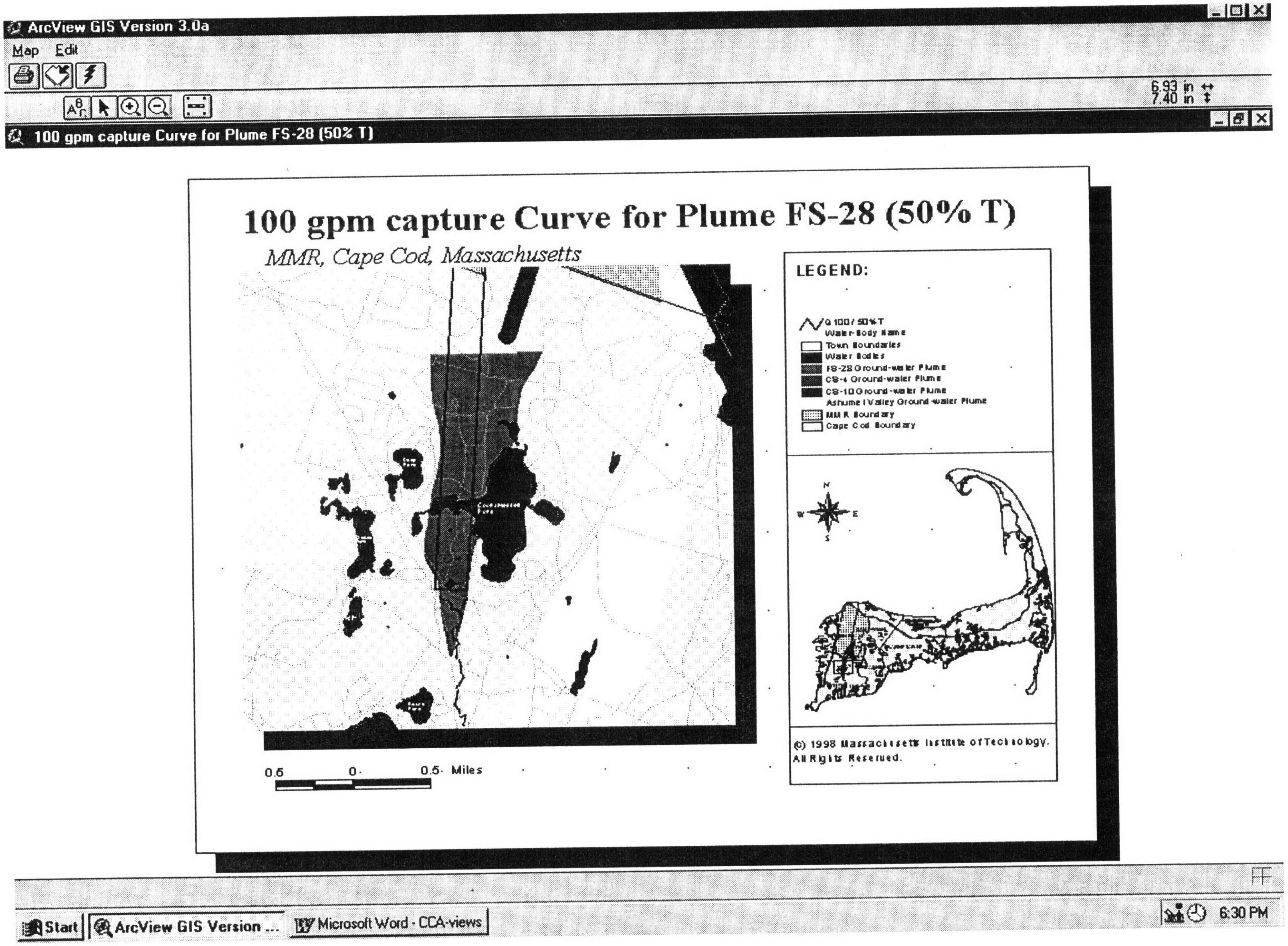
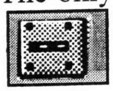
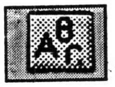
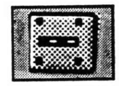
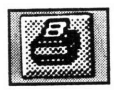
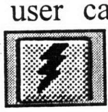


Figure 5-8: "Layout view" screen.

and tool buttons are different, and aside from zooming-in/out, the user has little control over the elements on the screen. The only tool buttons that allow the user to add something to the screen are the  and the  tool.

The  tool allows the user to add additional text to the map. The  tool allows the user to add a new scalebar to the map. This is only necessary when the scalebar automatically added to the map extends off the extent of the map. This will only occur when the user has zoomed-in to a scale less than 1:5,000. Before adding the new scalebar, the user should delete the old one by selecting the  tool, and selecting the "Delete" command under the **Edit** menu.

The user can print out the map by pressing the  tool or by selecting the "Print Map" command under the **Map** menu. The user can not revisit the map after it is closed or deleted, therefore, if the user is content with the map, he/she should print it out for future reference. The user can close the map using the  tool, or he/she can delete the map using the  tool. Either tool will send the user back to the main view.

5.4.4 Exiting

After the user is finished testing out the functionality of the CCA program, the user can exit the program simply by selecting the "Close Program" command under the **File** menu. The CCA program does not provide the user with the capability of saving the results generated during the session, therefore, all results will be lost upon exiting the session.

6. Conclusion

The process of designing a pump-and-treat system is complicated and time consuming. Although the results yielded by the CCA program should not be used for design purposes, they can be used as preliminary findings. The CCA program may reveal pumping scenarios that warrant further investigation, or it may illustrate those scenarios that are not applicable. Either way, the CCA program has the potential to be a time-saving tool for engineers working on the MMR.

The user-friendly nature of the program also lends itself to the general public. The MMR has eleven public action groups overseeing and ensuring proper clean-up of the ground-water plumes at the base. The CCA program has the capability of being served on the web, allowing these action groups, and anyone else interested in the MMR, to observe the current extent of the ground-water plumes and test whether the pump-and-treat systems approved by the MMRIRP are successful in containing the plumes.

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8. Appendices

Appendix A: CCA Program Scripts

Title: CCA.Index

Description: Opens the CCA program with the Index map showing

```
thisProject = av.GetProject
'gets active Project
viewIndex = thisProject.FindDoc ("Index Map")
indexWindow = viewIndex.GetWin
'gets the Index Map widow
if (indexWindow.IsOpen) then
  indexWindow.Activate
else
  indexWindow.Open
end
'the loop makes the Index Map active in case it was already open
'
av.delayedRun ("zoc.Begin","",10)
```

Title:CCA.Begin

Description: Opens the CCA welcome message and changes to the main view

```
'
thisProject = av.GetProject
'
MsgBox.Warning ("Welcome to the CCA Program!!", "WELCOME")
 'this message box only has an ok button
viewWindow = thisProject.FindDoc("Index Map")
indexWindow = viewWindow.GetWin
indexWindow.Close
 viewplumes = thisproject.FindDoc ("plumes")
 ZoomRect = Rect.Make (262601@807154, 70913@64722)
 viewplumes.GetDisplay.SetExtent(ZoomRect)
 plumes = viewplumes.GetWin
 TList = viewplumes.GetThemes
 for each t in TList
   t.SetVisible (true)
   t.SetLegendVisible (true)
   t.UpdateLegend
 end
 roads = viewplumes.FindTheme ("roads")
 if (roads.IsVisible) then
    roads.SetVisible (false)
    roads.SetLegendVisible (false)
 end
 if (plumes.IsOpen) then
   plumes.Activate
 else
   plumes.Open
 end
```

Name: CCA.Well
Description: Generates the capture curve

```
'
'GETS THE PROJECT
'
thisproject =av.GetProject
theview = thisproject.FindDoc ("Plumes")
theDpy = theview.GetDisplay
theGList = theView.GetGraphics
theSymWin = av.GetSymbolWin
aPaletteList = theSymWin.GetPalette.GetList( #PALETTE_LIST_MARKER )
theSymWin.SelectSymbol( aPaletteList.Get( 42 ))
aPaletteList.Get(42).SetSize (12)

'
'OPENS THE PLUMES DOCUMENT
'
viewPlumes = theview.GetWin
if (viewPlumes.IsOpen) then
  viewPlumes.Activate
else
  viewPlumes.Open
end
'
'GET USER-DEFINED INFO
'
av.ShowMsg ("Please click on the desired well location")
av.ClearMsg
'get the point
pointClick = theDpy.ReturnUserPoint
aPoint = pointClick.Clone
'make the well a point on the display
aGPoint = GraphicShape.Make (pointClick)
theGList.Add (aGPoint)
scroll = -1
w = theview.FindTheme ("Water Bodies")
scroll = w.GetFTab
polytest = w.GetFTab.FindField ("Shape")
for each rec in scroll
  shpVoid = w.GetFTab.ReturnValue (polytest,rec)
  if (shpVoid.Contains (pointClick)) then
    MsgBox.Warning ("Please relocate well.","Improper Well Location")
    theGList.SelectAll
    theGList.ClearSelected
    exit
  end
end
'
'get the pumping rate for zoc.analysis and label
aLabel = MsgBox.Input
("Please Enter the pumping rate in gallons per minute.","","")
```

```
if (nil = aLabel) then
  MsgBox.Warning ("Well Location Cancelled.","Warning")
  theGList.SelectAll
  theGList.ClearSelected
  exit
end
if (aLabel.AsNumber = 0) then
 MsgBox.Warning("Please enter a pumping rate greater than 0","WARNING")
 theGList.SelectAll
 theGList.ClearSelected
 exit
end
'
'get the %thickness of the aquifer
perTrans = MsgBox.Input
("Please enter the desired percent thickness of the aquifer captured by the well (1-100).","","")
if (nil = perTrans) then
  MsgBox.Warning ("Assuming 100% of the aquifer thickness is captured.","")
  perTrans = 100.AsString
end
if (perTrans.AsNumber = 0) then
 MsgBox.Warning("Please enter a percent thickness greater than 0","WARNING")
 theGList.SelectAll
 theGList.ClearSelected
 exit
end
'
'SELECT THE CLOSEST FEATURE
'
test = "Ground-water Plume"
minDistance = 999999999
featuresToCheck = -1
minrecord = -1
for each t in theview.GetThemes
  plumename = t.GetName
  if (plumename.Contains (test)) then
     featuresToCheck = t.GetFTab        'getting table
     shpFld = t.GetFTab.FindField ("Shape")
     for each rec in featuresToCheck
       shpCurrent = t.GetFTab.ReturnValue (shpFld,rec)
       if (shpCurrent.Contains (pointClick)) then
          minDistance = 0
          minrecord = rec
          finaltheme = featuresToCheck
          break
       else
         lineShp = shpCurrent.AsPolyline
         dist = shpCurrent.Distance (pointClick)
         if (dist < minDistance) then
           minDistance = dist
           minrecord = rec
           finaltheme = featuresToCheck
         end
       end
```

```
      end
    end
  end
  if (minrecord = -1) then
    MsgBox.Warning ("Unable to perform analysis.  Please relocate the well.","Warning")
    theGList.SelectAll
    theGList.ClearSelected
    exit
  end
'
'GET PRE-ASSIGNED INFORMATION
'
angle_rot = finaltheme.FindField ("angle_rot")
angleRot = finaltheme.ReturnValue (angle_rot, minrecord)
grad_h = finaltheme.FindField ("Gradient")
grad = finaltheme.ReturnValue (grad_h, minrecord)
'
'
'CALCULATE THE RECTANGLE
percentTrans = perTrans.AsNumber / 100
transMiss = percentTrans * 21100
pumpRate = aLabel.AsNumber
stagpoint = ((pumpRate / (grad * transMiss)) * 9.337 )  'D
stagpoint.SetFormat ("d.d")
maxwidth = stagpoint * 6.28                      'W
maxwidth.SetFormat ("d.d")
halfW = maxwidth / 2
newW= (0.55 * maxwidth) / 2
newW.SetFormat("d.d")
inDEG = ((newW - halfW) / -stagpoint)
alpha = inDEG.AsRadians
ratio = alpha.Tan
'areaZOC = (pumpRate * 3920.86)                   'A
'areaZOC.SetFormat ("d.d")
zocLength = newW / ratio                         '30% L
zocLength.SetFormat ("d.d")
'
'CALCULATE THE COORDINATES
originx = pointClick.GetX
originy = pointClick.GetY
oldLLx = - stagpoint
oldLLy = - (maxwidth / 2)
oldULx = - stagpoint
oldULy = (maxwidth / 2)
oldLRx = zocLength
oldLRy = - (maxwidth / 2)
oldURx = zocLength
oldURy = (maxwidth / 2)
'
'ROTATE THE COORDINATES
angleRad = angleRot.AsRadians
numC = angleRad.Cos                  'C
numS = angleRad.Sin                  'S
rotLLx = (oldLLx * numC) - (oldLLy * numS)
```

```
rotLLy = (oldLLx * numS) + (oldLLy * numC)
rotULx = (oldULx * numC) - (oldULy * numS)
rotULy = (oldULx * numS) + (oldULy * numC)
rotLRx = (oldLRx * numC) - (oldLRy * numS)
rotLRy = (oldLRx * numS) + (oldLRy * numC)
rotURx = (oldURx * numC) - (oldURy * numS)
rotURy = (oldURx * numS) + (oldURy * numC)
'
'TRANSLATE THE COORDINATES
newLLx = originx + rotLLx
newLLy = originy + rotLLy
newULx = originx + rotULx
newULy = originy + rotULy
newLRx = originx + rotLRx
newLRy = originy + rotLRy
newURx = originx + rotURx
newURy = originy + rotURy
'
'
'MAKE THE LINES
theGList.ClearSelected
rightLine = Line.Make (newLRx@newLRy, newLLx@newLLy)
bottomLine = Line.Make (newULx@newULy, newLLx@newLLy)
leftLine = Line.Make (newULx@newULy, newURx@newURy)
'topLine = Line.Make (newURx@newURy, newLRx@newLRy)
LineRG = GraphicShape.Make (rightline)
LineBG = GraphicShape.Make (bottomline)
LineLG = GraphicShape.Make (leftline)
'TGLine = GraphicShape.Make (topline)
theGList.Add (LineRG)
LineRG.SetSelected (true)
theGList.Add (LineBG)
LineBG.SetSelected (true)
theGList.Add (LineLG)
LineLG.SetSelected (true)
'
selLines = theGList.GetSelected
theGList.RemoveGraphic (LineRG)
theGList.RemoveGraphic (LineBG)
theGList.RemoveGraphic (LineLG)
'
'CONVERT THE GRAPHICS TO SHAPEFILE
if (selLines.Count = 0) then
 MsgBox.Warning ("No Graphics to Convert!","")
 theGList.SelectAll
 theGList.ClearSelected
 exit
end
'
ftPoint = False
ftLine = False
ftPolygon = False
ftUnknown = False
ftKount = 0
```

```
ftList = List.Make
'
for each gs in selLines
  s = gs.GetShape
  if (s.GetDimension = 0) then
    ftPoint = True
    ftList.Add("Point")
  elseif (s.GetDimension = 1) then
    ftLine = True
    ftList.Add("Line")
  elseif (s.getDimension = 2) then
    ftPolygon = True
    ftList.Add("Polygon")
  else
    ftUnknown = True
    ftList.Add("Unknown")
    MsgBox.Info("Unknown feature option","")
    theGList.SelectAll
    theGList.ClearSelected
    exit
  end
end
'
ftList.RemoveDuplicates
'
if (ftList.Count <> 1) then
  MsgBox.Error("Feature Type Mismatches","Select Only One Feature Type: Point, Line or Polygon")
  Return Nil
end
'
'
if (ftPoint = True) then
  class = Point
elseif (ftLine = True) then
  class = PolyLine
elseif (ftPolygon = True) then
  class = Polygon
else
  class = Nil
end
'
def = av.GetProject.MakeFileName("Q"+aLabel.AsString, "shp")
'
'
if (def <> nil) then
  tbl = FTab.MakeNew(def, class)
  if (tbl.HasError) then
    if (tbl.HasLockError) then
      MsgBox.Error("Unable to acquire Write Lock for file " + def.GetBaseName, "")
    else
      MsgBox.Error("Unable to create " + def.GetBaseName, "")
    end
    return nil
  end
```

```
  theIdField = Field.Make("ID", #FIELD_DECIMAL, 8, 0)
  'theIdField.SetVisible( TRUE )
  tbl.AddFields({theIdField})
  'tbl.SetEditable(False)
  'theNewTheme = FTheme.Make(tbl)
  'theNewTheme.SetName ("Q"+aLabel.AsString)
  'theNewFtab = theNewTheme.GetFtab
  theNewShapeField = tbl.FindField("Shape")
  theIDField = tbl.FindField("ID")
  'theView.AddTheme(theNewTheme)
  'theNewTheme.SetActive(TRUE)
  'theNewTheme.SetVisible(TRUE)
  'theView.SetEditableTheme(theNewTheme)
  'av.GetProject.SetModified(true)
end
'
'if (theNewFtab = Nil) then
'  theGList.SelectAll
'  theGList.ClearSelected
'  exit
'end
'
thePrj = theview.GetProjection
theKount = 0
for each g in selLines
  theKount = theKount + 1
  theShape = g.GetShape
  if ((theShape.Is(Line)) or (theShape.Is(PolyLine))) then
    theNewRec = tbl.AddRecord
    thePolyLine = theShape.asPolyLine
    if (thePrj.IsNull.Not) then
      thePolyLine = thePolyLine.ReturnUnprojected(thePrj)
    end
    tbl.SetValue(theNewShapeField,theNewRec,thePolyLine)
    tbl.SetValueNumber(theIDField,theNewRec,(theKount))
  else
    theGList.SelectAll
    theGList.ClearSelected
    exit
  end
end
tbl.SetEditable(false)
av.GetProject.SetModified (TRUE)
theNewTheme = FTheme.Make(tbl)
theNewTheme.SetName("Q"+aLabel.AsString++"/"++perTrans.AsString+"%T")
theview.Addtheme (theNewTheme)
theNewTheme.SetActive (TRUE)
'
theNewTheme.SetVisible (TRUE)
theLegend = theNewTheme.GetLegend
theSymbol = theLegend.GetSymbols.Get(0).SetWidth(3)
theNewTheme.UpdateLegend
' Updating the legend is used to apply your changes just as you would
' in the Legend Editor.
```

Name: CCA.DeleteQ

Title: Provides a menu for the user to choose which capture curve to delete '

```
'GETS THE PROJECT
'
thisproject =av.GetProject
theview = thisproject.FindDoc ("Plumes")
theDpy = theview.GetDisplay
theGList = theView.GetGraphics
QList = List.Make
testFlow = "Q"
for each t in theview.GetThemes
  plumename = t.GetName
  if (plumename.Contains (testFlow)) then
    QList.Insert (t)
  end
end
Kount = QList.Count
if (Kount = nil) then
  MsgBox.Warning ("There are no Capture Curves to delete.","")
  exit
end
'
myChoice = MsgBox.List (QList, "Please select the capture curve to delete:","")
'
if (nil = myChoice) then
  MsgBox.Warning("No capture curves were deleted","")
  exit
else
  theview.DeleteTheme (myChoice)
end
```

Name: CCA.CreateMap

Description: Creates a map of the current view

```
'written by Razavi, 1997
' This script is attached to a customized
' button in the view document interface.
' Executing this script will create a standard
' layout document from the current view.
'
' First create a new layout.
'
thisProject = av.GetProject
thisView = thisProject.FindDoc ("plumes")
stdLayout = Layout.Make
stdLayoutDpy = stdLayout.GetDisplay
stdLayoutGL = stdLayout.GetGraphics
'
' Set the layout page properties to
' landscape 11 x 8.5 with an all-around
' 0.00 inch margin.
'
```

```
marginRect = Rect.MakeXY ( 0.0, 0.0, 0.0, 0.0)
stdLayoutDpy.SetUnits (#UNITS_LINEAR_INCHES)
stdLayoutDpy.SetMargin (marginRect)
stdLayoutDpy.SetMarginVisible (True)
stdLayoutDpy.SetPageSize (Point.Make(11.0,8.5))
stdLayoutDpy.SetGridActive (False)
stdLayoutDpy.SetGridVisible (True)
stdLayoutDpy.SetGridMesh (Point.Make(1.0,1.0))
'
' Requests that place graphic objects on the
' layout require X and Y coordinates. The
' coordinates are based on the Display frame
' and not the PageDisplay.
' In order to use the coordinates of
' PageDisplay, the
' lower left X and Y for the PageDisplay is
' obtained. In the next code line this
' coordinate is stored in
' the oPt (origin point) object.
'
oPt = stdLayoutDpy.ReturnMarginExtent.ReturnOrigin
'
' Add a title and a subtitle to the page.
' Use Times Roman font and sizes of 24 and 18.
'
titleSymbol = TextSymbol.Make
titleSymbol.SetFont (
Font.Make("Times New Roman","Bold") )
titleSymbol.SetSize (36) 'size is in points
subtitleSymbol = titleSymbol.Clone
subtitleSymbol.SetSize (24)
subtitleSymbol.SetFont (Font.Make("Times New Roman","Italic"))
allTitles = MsgBox.Input (
"Please enter the title of the map","MAP TITLE","")
if (nil = allTitles) then
  MsgBox.Warning ("Stopped making map.","")
  exit
else
  pTitle = GraphicText.Make (
  allTitles, oPt+Point.Make(0.67,7.80) )
  pTitle.SetSymbols ({titleSymbol})
  pTitle.SetAngle (0)
  stdLayoutGL.Add (pTitle)
  subtitle = GraphicText.Make (
  "MMR, Cape Cod, Massachusetts", oPt+Point.Make(0.94,7.4) )
  subtitle.SetSymbols ({subtitleSymbol})
  subtitle.SetAngle (0)
  stdLayoutGL.Add (subtitle)
end
'SET NAME
stdLayout.SetName (allTitles)
'
LegendSymbol = TextSymbol.Make
LegendSymbol.SetFont (Font.Make ("Arial", "Bold"))
```

```
LegendSymbol.SetSize (16)
LegSym = GraphicText.Make ("LEGEND:", oPt+Point.Make(7.42,7.17) )
LegSym.SetSymbols ({LegendSymbol})
stdLayoutGL.Add (LegSym)
Copyright = TextSymbol.Make
Copyright.SetFont (Font.Make ("Arial","Normal"))
Copyright.SetSize (12)
copyText = "(c) 1998 Massachusetts Institute of Technology."+NL+"All Rights Reserved."
CopyRt = GraphicText.Make (copyText, oPt+Point.Make(7.3,1.04))
CopyRt.SetSymbols ({Copyright})
stdLayoutGL.Add (CopyRt)
'
' Add view frames. The primary view frame
' shows the active view at its current extent,
' while the locator view frame shows the
' active frame zoomed to its extent with
' a rectangle depicting the area of primary view.
'
' The primary view is placed at point 1,1 with
' a shadow box.
'
vFill = RasterFill.Make
vFill.SetStyle (#RASTERFILL_STYLE_SOLID)
vFill.SetColor (Color.GetWhite)
vFill.SetOutlined (true)
vFill.SetOLColor (Color.GetBlack)
vRect = Rect.Make (
oPt+Point.Make (0.60,1.53),
Point.Make (6.0,5.80) )
vRectGr = GraphicShape.Make (vRect)
vRectGr.SetSymbol (vFill)
stdLayoutGL.Add (vRectGr)
vFrame = ViewFrame.make (vRect)
vFrame.SetSymbol (vFill)
vFrame.SetView (thisView,true)
vFrame.SetScalePreserved (false)
stdLayoutGL.Add (vFrame)
'
' Add a shadow box to the primary view.
'
sFill = vFill.Clone
sFill.SetColor (Color.GetBlack)
sRect = vFrame.GetBounds
shadowGr = GraphicShape.Make (sRect)
shadowGr.Offset (Point.Make(0.25,-0.25))
shadowGr.SetSymbol (sFill)
stdLayoutGL.UnselectAll
shadowGr.SetSelected (true)
stdLayoutGL.Add (shadowGr)
stdLayoutGL.MoveSelectedToBack
stdLayoutGL.UnselectAll
'
' Add the locator map at 1,5.5 inches.
' The locator map is based on a cloned view that
```

```
' displays the view's full extent.
'
lRect = Rect.Make (
oPt+Point.Make(7.23,1.67),
Point.Make (3.60,3.09) )
lFrame = ViewFrame.Make (lRect)
lFrame.SetSymbol (vFill)
fullView = thisView.Clone
roads = fullView.FindTheme ("roads")
if (roads.IsVisible) then
  roads.SetVisible (false)
  roads.SetLegendVisible (false)
end
fullView.GetDisplay.SetExtent
(fullView.ReturnExtent)
fullView.SetName("Full View")
lFrame.SetView (fullView, True)
lFrame.SetScalePreserved (False)
stdLayoutGL.Add (lFrame)
'
' Draw a box in the locator map to show
' the extent of the primary view. This box is
' actually drawn on the view display and
' seen on the layout document.
'
boxFill = vFill.Clone
boxFill.SetStyle (#RASTERFILL_STYLE_EMPTY)
boxFill.SetOutlined (True)
boxFill.SetOlColor (Color.GetBlack)
boxFill.SetOlWidth (2)
vFrameExtent = thisView.GetDisplay.ReturnVisExtent
lBox = GraphicShape.Make (vFrameExtent)
lBox.SetSymbol (boxFill)
fullViewGL = fullView.GetGraphics
fullViewGL.Add (lBox)
'
' Draw boxes to hold the scale bar,
' north arrow, and legend. AddBatch is
' used to add the remaining items to
' the layout.
'
aPen = BasicPen.Make
aPen.SetColor (Color.GetBlack)
infoBox = Polygon.Make ( { {
oPt+Point.Make (7.25,0.77),
oPt+Point.Make (7.25,7.48),
oPt+Point.Make (10.5,7.48),
oPt+Point.Make (10.5,0.77) } } )
infoBoxGr = GraphicShape.make (infoBox)
infoBoxGr.SetSymbol (aPen)
stdLayoutGL.AddBatch (infoBoxGr)
'
line1 = Line.Make (
oPt+Point.Make (7.25,4.95),
```

```
oPt+Point.Make (10.5,4.95) )
line1Gr = GraphicShape.Make (line1)
line1Gr.SetSymbol (aPen)
stdLayoutGL.AddBatch (line1Gr)
'
line2 = Line.Make (
oPt+Point.Make (7.25,1.5),
oPt+Point.Make (10.5,1.5) )
line2Gr = GraphicShape.Make (line2)
line2Gr.SetSymbol (aPen)
stdLayoutGL.AddBatch (line2Gr)
'
' Add scale bar.
'
sbRect = Rect.Make (
oPt+Point.Make (0.86,0.77),
Point.Make (5.70,0.32) )
sbFrame = ScalebarFrame.Make (sbRect)
sbFrame.SetUnits (#UNITS_LINEAR_MILES)
sbFrame.SetStyle (#SCALEBARFRAME_STYLE_ALTFILLED)
sbFrame.SetViewFrame (vFrame)
sbFrame.SetInterval (0.5)
sbFrame.SetIntervals (1)
stdLayoutGL.AddBatch (sbFrame)
'
' Add north arrow.
'
naRect = Rect.Make (
oPt+Point.Make (7.37, 3.85),
Point.Make (0.8, 0.80) )
naGr = NorthArrow.Make (naRect)
' Retrieve a predefined north arrow from
' the north.def file.
northArrowFile = FileName.Make
("d:\MMR\north.def")
northArrowODB = ODB.Open (northArrowFile)
if (nil = northArrowODB) then
  MsgBox.Error
 ("Unable to open north.def object database",
  "")
  exit
end
northArrowList = northArrowODB.Get(0)
anArrow = northArrowList.Get(1)
naGr.SetArrow (anArrow)
stdLayoutGL.AddBatch (naGr)
'
' Add the legend.
'
'LegSym = TextSymbol.Make
'LegSym.SetFont (Font.Make("Arial","Bold") )
'LegSym.SetSize (12) 'size is in points
lgRect = Rect.Make (
oPt+Point.Make (7.43,5.22),
```

```
Point.Make (2.6,1.8) )
lgFrame = LegendFrame.Make (lgRect)
lgFrame.SetViewFrame (vFrame)
'lgFrame.SetSymbols ({LegSym})
stdLayoutGL.AddBAtch (lgFrame)
'
' End the AddBatch.
'
stdLayoutGL.EndBatch
'
' Open the layout document.
thisViewWin = thisView.GetWin
thisViewWin.Minimize
stdLayoutWin = stdLayout.GetWin
stdLayoutWin.Open
stdLayoutWin.Maximize
```

Name: CCA.CloseMap

Description: Closes the current Map

```
theDoc = av.GetActiveDoc
theDoc.GetWin.Close
thisproject = av.GetProject
plumes = thisproject.FindDoc("Plumes")
plumesWin = plumes.GetWin
if (plumesWin.IsOpen) then
  plumesWin.Maximize
else
  plumesWin.Open
end
```

Name: CCA.DeleteMap

Description: Deletes the current map

```
theDoc = av.GetActiveDoc
check = MsgBox.LongYesNo
 ("Are you sure you want to delete this map?","DELETE MAP" ,False)
if (check) then
  av.GetProject.RemoveDoc(theDoc)
else
  MsgBox.Info ("No map was deleted.","")
  exit
end
```

Name: CCA.Pan

Description: Pans to the user-defined extent, shuts off the themes not visible in the new extent

```
av.GetProject.SetModified(true)
theView = av.GetActiveDoc
theView.GetDisplay.Pan
theDpy = theview.GetDisplay
VRect = theDpy.ReturnVisExtent
```

```
testFlow = "Q"
test = "Ground-water Plume"
featuresToCheck = -1
for each t in theview.GetThemes
  plumename = t.GetName
  if (plumename.Contains (testFlow)) then
    featuresToCheck = t.GetFTab
    shpFLd = t.GetFTab.FindField ("Shape")
    for each rec in featuresToCheck
      shpCurrent = t.GetFTab.ReturnValue (shpFld,rec)
      linePoint = shpCurrent.ReturnCenter
      if (VRect.Contains (linePoint)) then
        t.SetVisible (true)
        t.SetLegendVisible (true)
        t.UpdateLegend
        break
      else
        t.SetVisible (false)
        t.SetLegendVisible (false)
        t.UpdateLegend
      end
    end
  elseif (plumename.Contains (test)) then
    featuresToCheck = t.GetFTab        'getting table
    shpFld = t.GetFTab.FindField ("Shape")
    for each rec in featuresToCheck
      shpCurrent = t.GetFTab.ReturnValue (shpFld,rec)
      if (VRect.Intersects(shpCurrent)) then
        t.SetVisible (true)
        t.SetLegendVisible (true)
        t.UpdateLegend
        break
      else
        t.SetVisible (false)
        t.SetLegendVisible (false)
        t.UpdateLegend
      end
    end
  end
end
```

Name: CCA.ZoomIn
Description: Attached to the zoom-in tool, requires the user to drag a rectangle around the view of interest, shuts off the themes not visible in the new extent

```
av.GetProject.SetModified(true)
theView = av.GetActiveDoc
r = theview.ReturnUserRect
d = theview.GetDisplay
if (r.IsNull) then
 d.ZoomIn(125)
 d.PanTo(d.ReturnUserPoint)
```

```
else
 d.ZoomToRect(r)
end
theDpy = theview.GetDisplay
VRect = theDpy.ReturnVisExtent
testFlow = "Q"
test = "Ground-water Plume"
featuresToCheck = -1
for each t in theview.GetThemes
  plumename = t.GetName
  if (plumename.Contains (testFlow)) then
    featuresToCheck = t.GetFTab
    shpFLd = t.GetFTab.FindField ("Shape")
    for each rec in featuresToCheck
      shpCurrent = t.GetFTab.ReturnValue (shpFld,rec)
      linePoint = shpCurrent.ReturnCenter
      if (VRect.Contains (linePoint)) then
        t.SetVisible (true)
        t.SetLegendVisible (true)
        t.UpdateLegend
        break
      else
        t.SetVisible (false)
        t.SetLegendVisible (false)
        t.UpdateLegend
      end
    end
  elseif (plumename.Contains (test)) then
     featuresToCheck = t.GetFTab        'getting table
     shpFld = t.GetFTab.FindField ("Shape")
     for each rec in featuresToCheck
       shpCurrent = t.GetFTab.ReturnValue (shpFld,rec)
       if (VRect.Intersects(shpCurrent)) then
          t.SetVisible (true)
          t.SetLegendVisible (true)
          t.UpdateLegend
          break
       else
          t.SetVisible (false)
          t.SetLegendVisible (false)
          t.UpdateLegend
       end
     end
  end
end
```

Name: CCA.ZoomInMenu

Description: Attached to the Zoom In menu, zooms in to the center of the display, shuts off the themes not visible in the new extent

```
av.GetProject.SetModified(true)
theView = av.GetActiveDoc
```

```
theView.GetDisplay.ZoomIn(125)
theDpy = theview.GetDisplay
VRect = theDpy.ReturnVisExtent
testFlow = "Q"
test = "Ground-water Plume"
featuresToCheck = -1
for each t in theview.GetThemes
  plumename = t.GetName
  if (plumename.Contains (testFlow)) then
    featuresToCheck = t.GetFTab
    shpFLd = t.GetFTab.FindField ("Shape")
    for each rec in featuresToCheck
      shpCurrent = t.GetFTab.ReturnValue (shpFld,rec)
      linePoint = shpCurrent.ReturnCenter
      if (VRect.Contains (linePoint)) then
        t.SetVisible (true)
        t.SetLegendVisible (true)
        t.UpdateLegend
        break
      else
        t.SetVisible (false)
        t.SetLegendVisible (false)
        t.UpdateLegend
      end
    end
  elseif (plumename.Contains (test)) then
    featuresToCheck = t.GetFTab        'getting table
    shpFld = t.GetFTab.FindField ("Shape")
    for each rec in featuresToCheck
      shpCurrent = t.GetFTab.ReturnValue (shpFld,rec)
      if (VRect.Intersects(shpCurrent)) then
        t.SetVisible (true)
        t.SetLegendVisible (true)
        t.UpdateLegend
        break
      else
        t.SetVisible (false)
        t.SetLegendVisible (false)
        t.UpdateLegend
      end
    end
  end
end
```

Name: CCA.ZoomOut

Description: Attached to the zoom-out button, requires the user to draw a rectangle around the area of interest, shuts off the themes not visible in the new extent

```
av.GetProject.SetModified(true)
theview = av.GetActiveDoc
r = theview.ReturnUserRect
d = theview.GetDisplay
if (r.IsNull.not) then
```

```
  ext = d.ReturnExtent
  ext.Scale(ext.GetWidth / r.GetWidth)
  d.ZoomToRect(ext)
else
  d.ZoomOut(125)
  d.PanTo(d.ReturnUserPoint)
end
theDpy = theview.GetDisplay
VRect = theDpy.ReturnVisExtent
testFlow = "Q"
test = "Ground-water Plume"
featuresToCheck = -1
for each t in theview.GetThemes
  plumename = t.GetName
  if (plumename.Contains (testFlow)) then
    featuresToCheck = t.GetFTab
    shpFLd = t.GetFTab.FindField ("Shape")
    for each rec in featuresToCheck
      shpCurrent = t.GetFTab.ReturnValue (shpFld,rec)
      linePoint = shpCurrent.ReturnCenter
      if (VRect.Contains (linePoint)) then
        t.SetVisible (true)
        t.SetLegendVisible (true)
        t.UpdateLegend
        break
      else
        t.SetVisible (false)
        t.SetLegendVisible (false)
        t.UpdateLegend
      end
    end
  elseif (plumename.Contains (test)) then
    featuresToCheck = t.GetFTab        'getting table
    shpFld = t.GetFTab.FindField ("Shape")
    for each rec in featuresToCheck
      shpCurrent = t.GetFTab.ReturnValue (shpFld,rec)
      if (VRect.Intersects(shpCurrent)) then
        t.SetVisible (true)
        t.SetLegendVisible (true)
        t.UpdateLegend
        break
      else
        t.SetVisible (false)
        t.SetLegendVisible (false)
        t.UpdateLegend
      end
    end
  end
end
```

Name: CCA.ZoomOutMenu

Description: Attached to the zoom-out menu, zooms-out to the center of the display, shuts off the themes not visible in the new extent

```
av.GetProject.SetModified(true)
theView = av.GetActiveDoc
theView.GetDisplay.ZoomOut(125)
theDpy = theview.GetDisplay
VRect = theDpy.ReturnVisExtent
testFlow = "Q"
test = "Ground-water Plume"
featuresToCheck = -1
for each t in theview.GetThemes
  plumename = t.GetName
  if (plumename.Contains (testFlow)) then
    featuresToCheck = t.GetFTab
    shpFLd = t.GetFTab.FindField ("Shape")
    for each rec in featuresToCheck
      shpCurrent = t.GetFTab.ReturnValue (shpFld,rec)
      linePoint = shpCurrent.ReturnCenter
      if (VRect.Contains (linePoint)) then
        t.SetVisible (true)
        t.SetLegendVisible (true)
        t.UpdateLegend
        break
      else
        t.SetVisible (false)
        t.SetLegendVisible (false)
        t.UpdateLegend
      end
    end
  elseif (plumename.Contains (test)) then
     featuresToCheck = t.GetFTab        'getting table
     shpFld = t.GetFTab.FindField ("Shape")
     for each rec in featuresToCheck
       shpCurrent = t.GetFTab.ReturnValue (shpFld,rec)
       if (VRect.Intersects(shpCurrent)) then
          t.SetVisible (true)
          t.SetLegendVisible (true)
          t.UpdateLegend
          break
       else
          t.SetVisible (false)
          t.SetLegendVisible (false)
          t.UpdateLegend
       end
     end
  end
end
```

Name: CCA.zoomtoSel

Description: Zooms to the extent of the selected theme, shuts off the themes not visible in the new extent

```
thisProject = av.GetProject
theview = thisProject.FindDoc ("Plumes")
indexWindow = theview.GetWin
'gets the Index Map widow
if (indexWindow.IsOpen) then
   indexWindow.Activate
else
   indexWindow.Open
end
'the loop makes the Index Map active in case it was already open

mylist = theview.GetThemes
mychoice = MsgBox.List(mylist,"Choose a theme to zoom to:","")
'
if (nil = mychoice) then
  MsgBox.Warning("Ceasing zoom","Warning")
  exit
else (mychoice.IsActive.Not)
  mychoice.SetActive (true)
  roads = theview.FindTheme ("roads")
  roads.SetVisible (true)
  theview.GetDisplay.SetExtent(mychoice.ReturnExtent.Scale (1.5))
  'turns off the active theme
  mychoice.SetActive (false)
end
'
'TURNS OFF THE VIEWS NOT IN DISPLAY
theDpy = theview.GetDisplay
VRect = theDpy.ReturnVisExtent
testFlow = "Q"
test = "Ground-water Plume"
featuresToCheck = -1
for each t in theview.GetThemes
  plumename = t.GetName
  if (plumename.Contains (testFlow)) then
    featuresToCheck = t.GetFTab
    shpFLd = t.GetFTab.FindField ("Shape")
    for each rec in featuresToCheck
      shpCurrent = t.GetFTab.ReturnValue (shpFld,rec)
      linePoint = shpCurrent.ReturnCenter
      if (VRect.Contains (linePoint)) then
        t.SetVisible (true)
        t.SetLegendVisible (true)
        t.UpdateLegend
        break
      else
        t.SetVisible (false)
        t.SetLegendVisible (false)
        t.UpdateLegend
      end
```

```
    end
  elseif (plumename.Contains (test)) then
    featuresToCheck = t.GetFTab        'getting table
    shpFld = t.GetFTab.FindField ("Shape")
    for each rec in featuresToCheck
      shpCurrent = t.GetFTab.ReturnValue (shpFld,rec)
      if (VRect.Intersects(shpCurrent)) then
        t.SetVisible (true)
        t.SetLegendVisible (true)
        t.UpdateLegend
        break
      else
        t.SetVisible (false)
        t.SetLegendVisible (false)
        t.UpdateLegend
      end
    end
  end
end
```

Name: CCA.Exit

Description: Closes the CCA program

```
theProject = av.GetProject
Plumes = theProject.FindDoc ("plumes")
testFlow = "Q"
ThemeList = Plumes.GetThemes
Check = MsgBox.LongYesNo("Are you sure you want to close the program?","CLOSE PROGRAM", FALSE)
if (Check) then
  for each t in ThemeList
    plumename = t.GetName
    if (plumename.Contains (testFlow)) then
      t.SetActive (TRUE)
    end
  end
  thmList = {}
  for each t in Plumes.GetActiveThemes
    if (t.CanDeleteFromView) then
      thmList.Add(t)
    end
  end
'
  thmList2 = thmlist.clone
'
  for each t in thmList2
   Plumes.DeleteTheme(t)
  end
'
  av.GetProject.SetModified(true)
  myLayout = av.FindGUI ("Layout")
  listDocs = theproject.GetDocsWithGroupGUI(myLayout)
  listDocs2 = listDocs.clone
  if (nil <> listDocs2) then
   for each l in listDocs2
```

```
      av.GetProject.RemoveDoc( 1 )
    end
   end
   theGList = Plumes.GetGraphics
   theGList.SelectAll
   theGList.ClearSelected
   av.PurgeObjects
   theProject.Close
else
  exit
end
```

Appendix B: Estimation of the Regional Transmissivity used in the CCA Program.

Guswa and LeBlanc (1985) created a three-dimensional, finite-difference flow model to describe the behavior of ground-water throughout Cape Cod. The value of regional transmissivity used in the CCA program was calculated using the transmissivity layers created for this model. Figures A-1 through A-4 illustrate the transmissivity layers created by Guswa and LeBlanc that were used to develop a weighted average of the regional transmissivity.

Table A-1 lists the variables and values used to estimate the regional transmissivity for the four towns abutting the MMR (Bourne, Sandwich, Falmouth, Mashpee). The transmissivity was defined by town because the town boundaries approximated equal quadrants. "T_i" represents the transmissivity depicted in Figures A-1 through A-4. The "percent of area with T_i" column represents the estimated percent of town area with the given T_i. The variable T_{frac} represents the transmissivity of the percent area previously defined. The "T_{town}" column represents the transmissivity of each town and the column "T_{layer}" represents the total transmissivity for each layer (Figures A-1 through A-4). The variables were quantified using Figures A-1 through A-4 and the following equations:

$$T_{frac} = T_i * \left(\frac{\%area}{100}\right) \qquad (1)$$

$$Ttown_i = \sum Tfrac_i \qquad (2)$$

$$Tlayer_j = \sum Ttown_j \qquad (3)$$

The regional transmissivity was calculated by summing the values of T_{layer} for layers 1 through 4 and was calculated to be approximately 21,000 ft^2/d.

$$Tregional = \sum Tlayer = 21{,}000$$

Table B-1: Values and variables used to calculate the regional transmissivity.

	Town	T_i (ft^2/d)	Percent of area with T_i (ft^2/d)	T_{frac} (ft^2/d)	T_{town}(ft^2/d)	T_{layer} (ft^2/d)
layer 1	Bourne	0	100	0	0	2847
	Sandwich	0	90	0	5	
		50	10	5		
	Falmouth	0	60	0	2132.5	
		50	15	7.5		
		10000	20	2000		
		2500	5	125		
	Mashpee	50	60	30	11030	
		30000	30	9000		
		20000	10	2000		
layer 2	Bourne	2500	45	1125	3250	5649
		5000	35	1750		
		7500	5	375		
		0	15	0		
	Sandwich	5000	5	250	4750	
		2500	45	1125		
		7500	45	3375		
	Falmouth	5000	45	2250	8875	
		7500	35	2625		
		20000	20	4000		
	Mashpee	7500	50	3750	4555	
		2000	40	800		
		50	10	5		
layer 3	Bourne	50	20	10	8010	6707
		5000	40	2000		
		15000	40	6000		
	Sandwich	5000	50	2500	3015	
		50	30	15		
		2500	20	500		
	Falmouth	5000	70	3500	8000	
		15000	30	4500		
	Mashpee	5000	60	3000	9000	
		15000	40	6000		
layer 4	Bourne	1250	45	562.5	5070	5727
		12500	20	2500		
		10000	20	2000		
		50	15	7.5		
	Sandwich	1250	80	1000	3000	
		10000	20	2000		
	Falmouth	1250	10	125	9875	
		5000	20	1000		
		12500	70	8750		
	Mashpee	5000	50	2500	4250	
		1250	40	500		
		12500	10	1250		

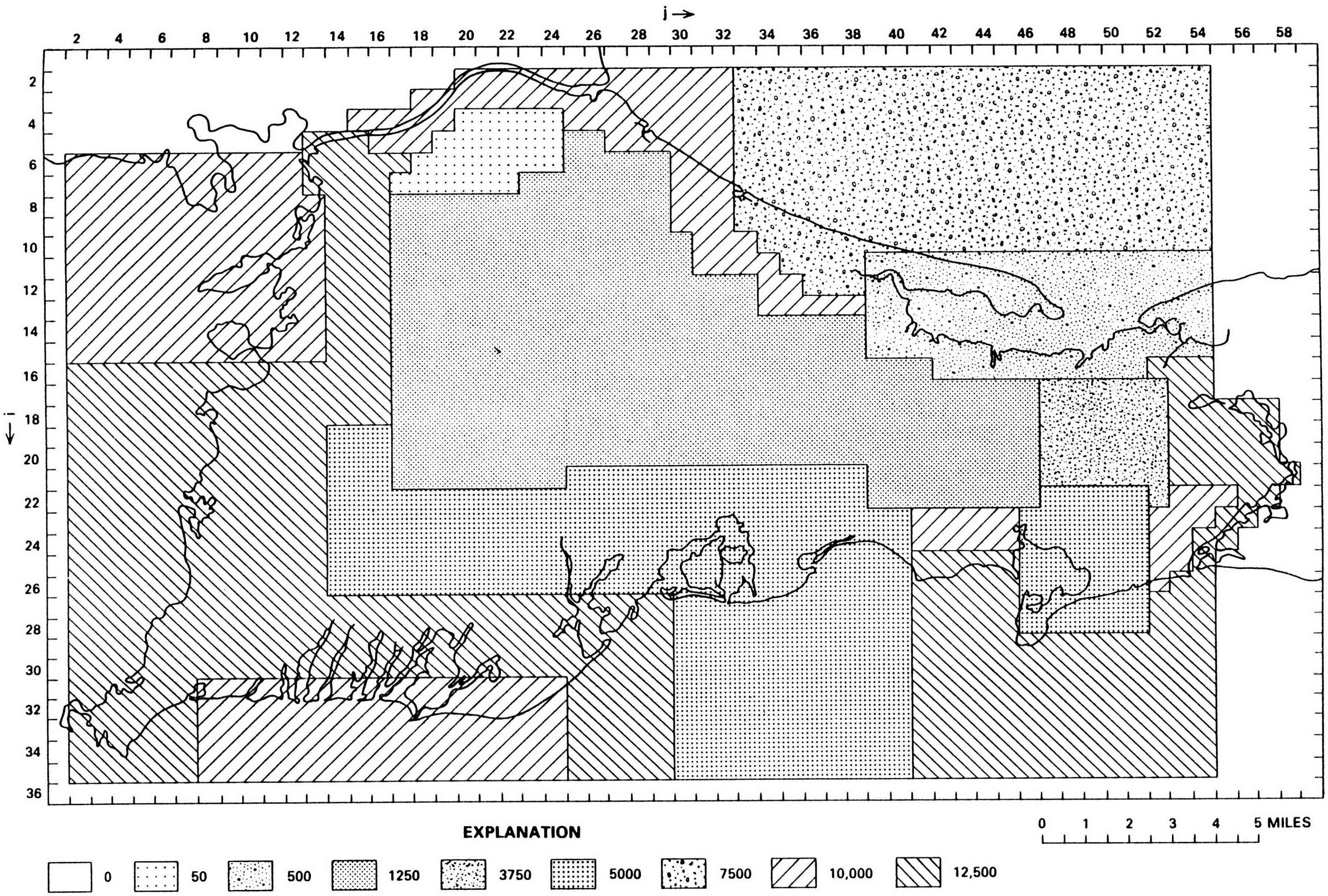

Figure A-1: Transmissivity layer 1 (Guswa and LeBlanc, 1985).

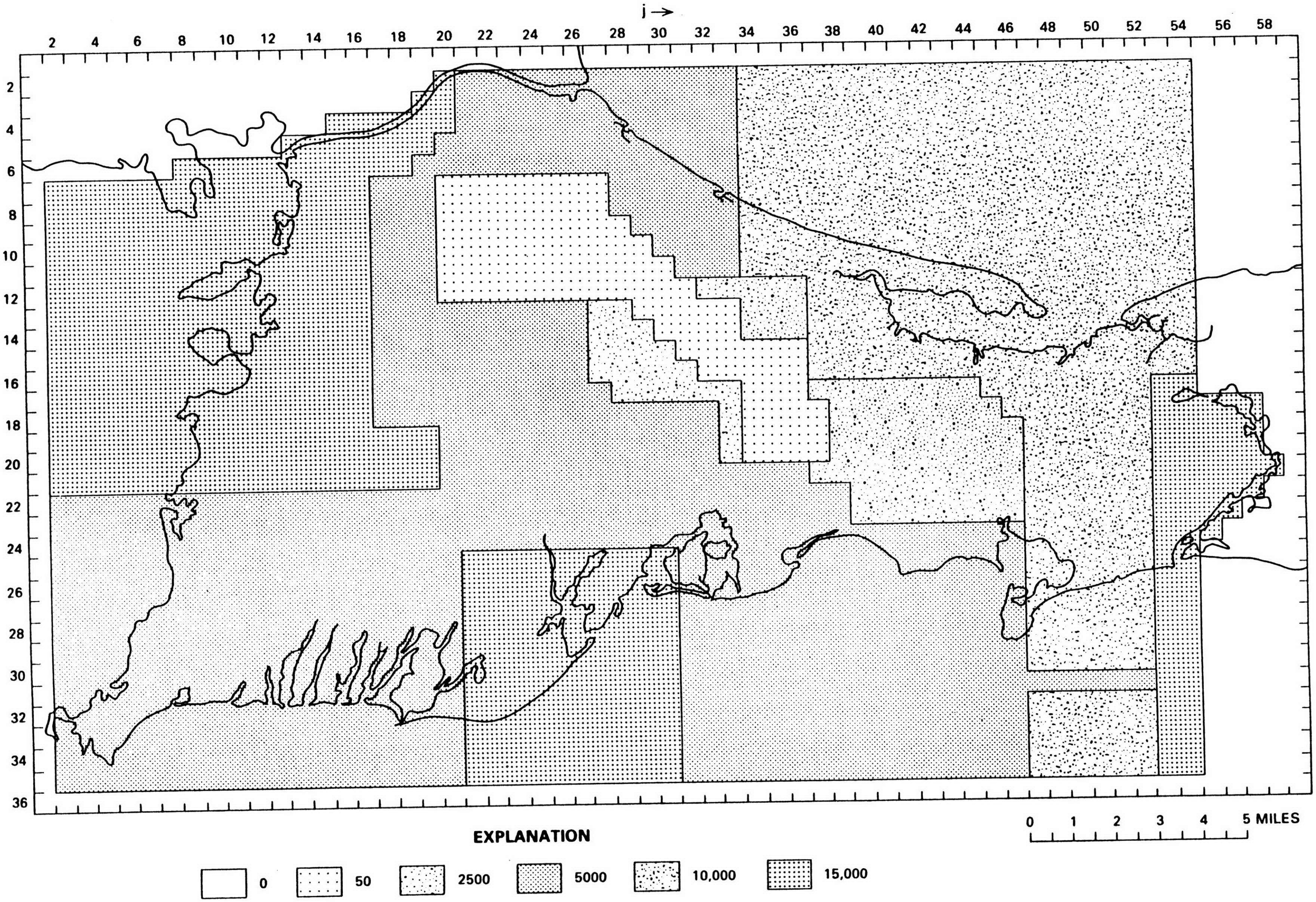

Figure A-2: Transmissivity layer 2 (Guswa and LeBlanc, 1985).

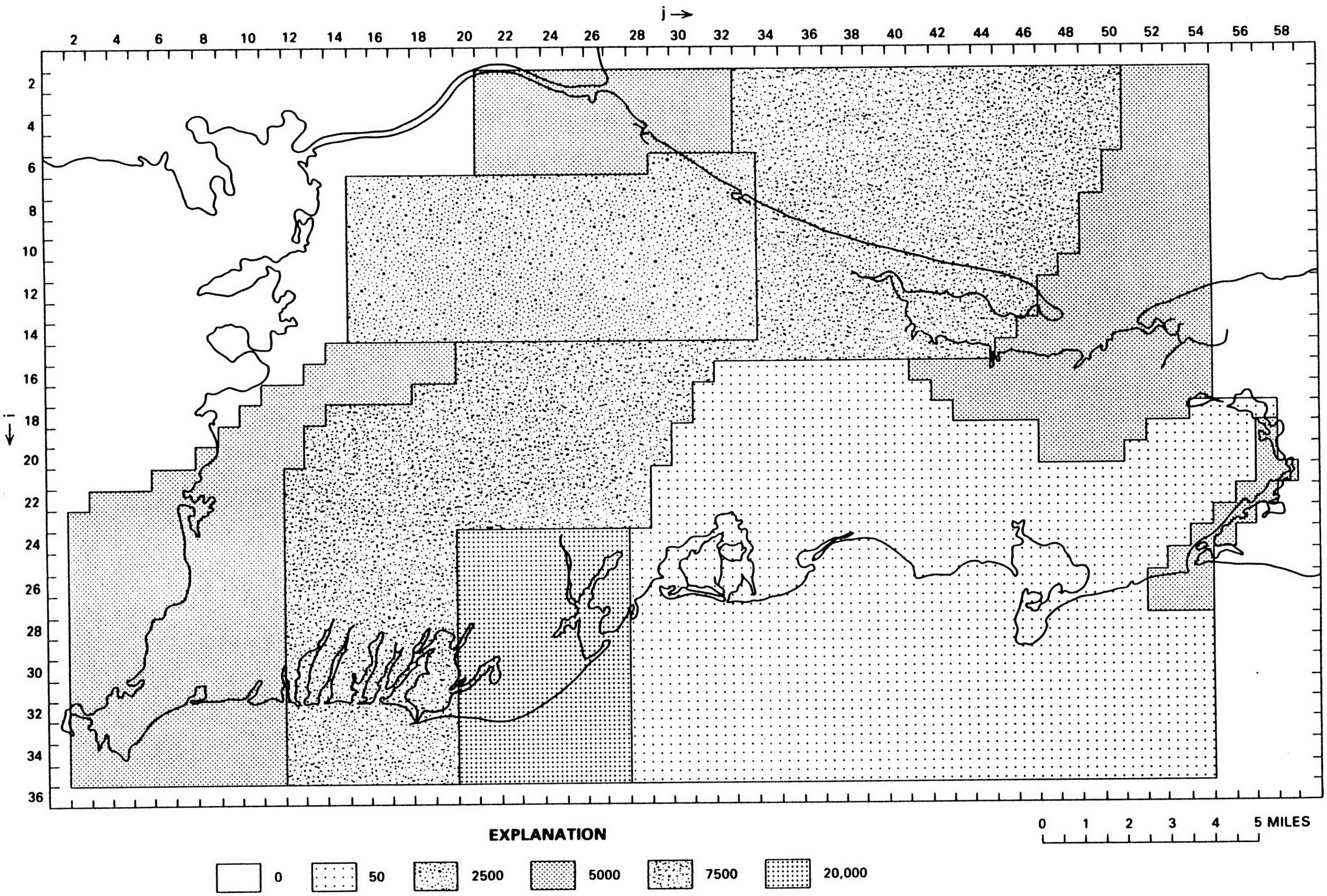

Figure A-3: Transmissivity layer 3 (Guswa and LeBlanc, 1985).

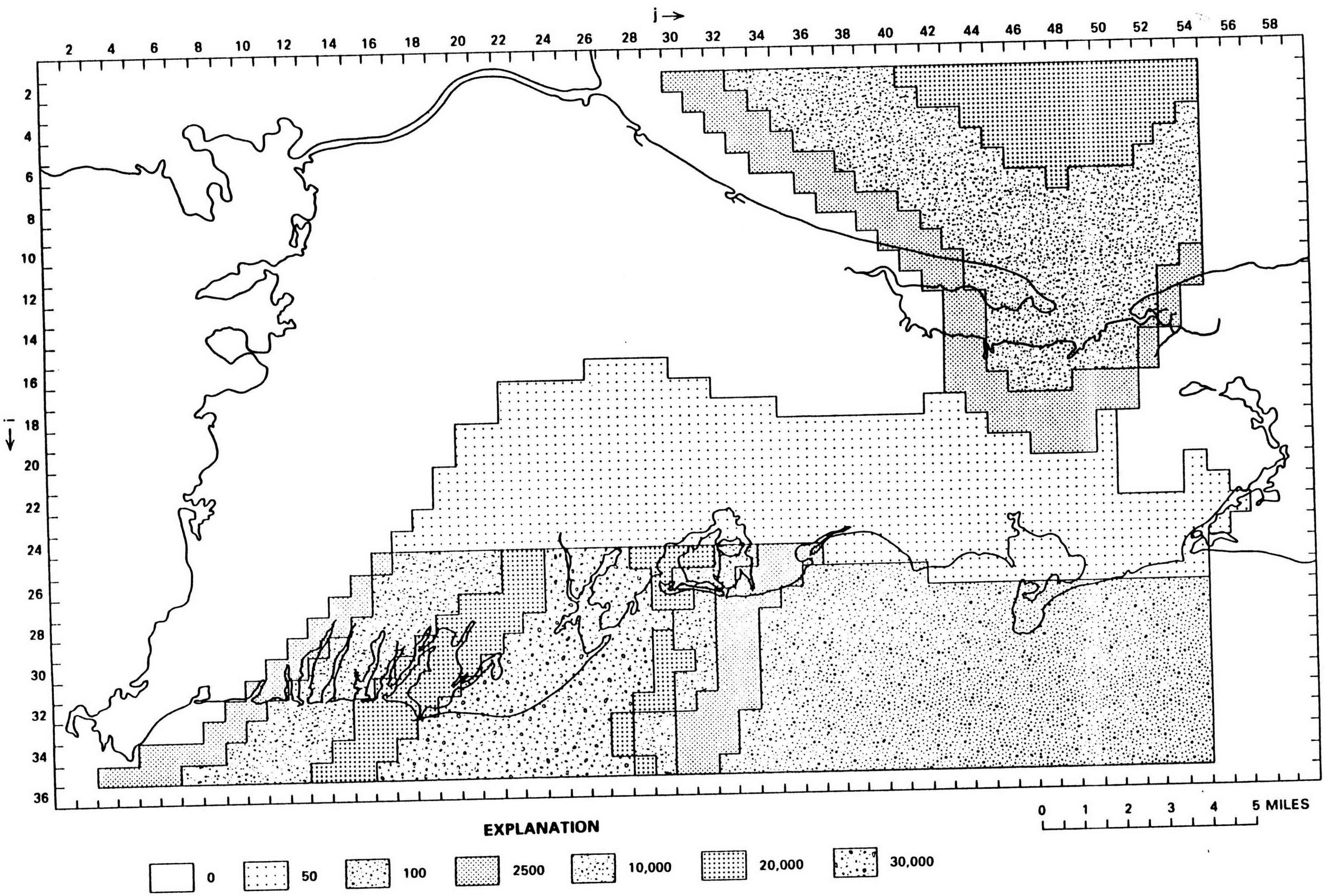

Figure A-4: Transmissivity layer 4 (Guswa and LeBlanc, 1985).

Appendix C: Estimation of the Magnitude and Direction of Hydraulic Gradients used in the CCA Program.

Figure C-1 illustrates the hydraulic gradients assigned to each plume. The general direction of each gradient was created by approximating the perpendicular to the ground-water contours. The ground-water plumes were used as guidelines for the gradient approximation.

The magnitude and direction of the hydraulic gradient was calculated using the dimensions of the gradients illustrated in Figure C-1. The magnitude of the gradient was estimated by the following equation:

$$I = \frac{\text{Change in head (ft)}}{\text{Length of gradient (m)}} * \frac{1 \text{ m}}{3.281 \text{ ft}}$$

The change in head was obtained by subtracting the difference between contours over the length of the gradient. The length of the gradient was obtained by using the distance function in ArcView. Table C-1 lists the length and change in head for each gradient. The direction of the gradient was obtained by plotting the x and y coordinates of each gradient, fitting an equation to the line, and calculating the angle between the gradient and the x-axis by taking the inverse tangent of the slope of the line. Figures C-2 through C-8 illustrate the plots used to calculate this angle. The slope and direction for each gradient are also listed in Table C-1.

Table C-1: Hydraulic gradient characteristics.

Ground-water Plume	Change in head (ft)	Length of gradient (m)	Magnitude of gradient (I)	Slope of gradient	Direction of gradient relative to the x-axis (degrees)
FS-28	20	3636	0.0017	14.76	86.13
FS-12	3	1460	0.0006	-2.32	-66.70
CS-4	15	2811	0.0016	2.97	71.40
Ashumet Valley	10	2528	0.0012	-4.50	-77.47
	20	3637	0.0017	2.28	66.32
	20	3536	0.0017	3.21	72.70
	5	456	0.0033	14.50	86.05
CS-10	10	3476	0.00088	1.14	48.74
	10	1926	0.0016	-2.34	-66.86
SD-5	10	1662	0.0018	-11.91	-85.20
	5	1148	0.0013	-0.90	-41.98
LF-1	30	1880	0.0049	0.26	14.57
	45	5493	0.0025	0.40	21.80

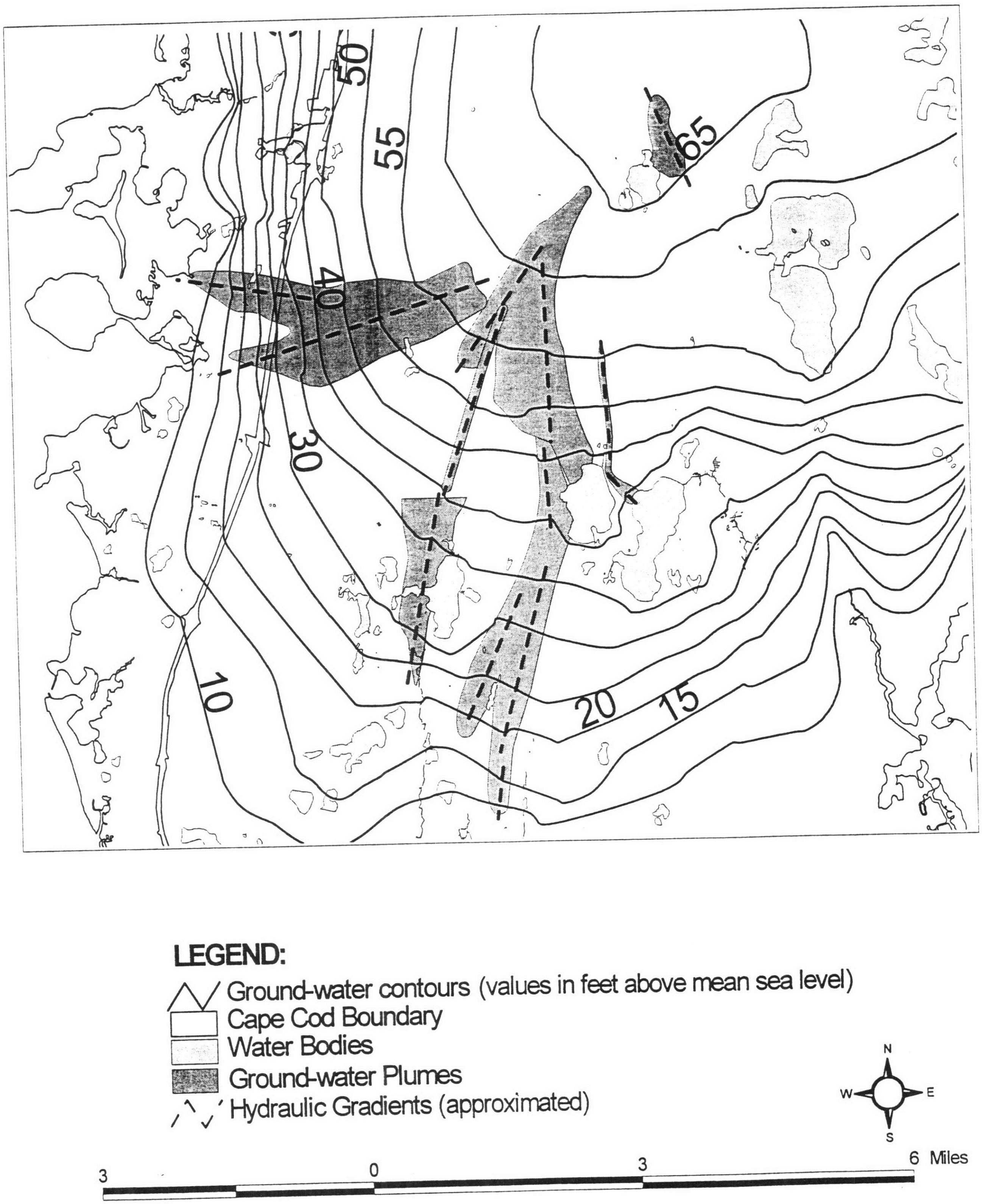

Figure A-1: Hydraulic gradients used in the CCA program.

Figure C-2: Plot of hydraulic gradient for ground-water plume FS-28.

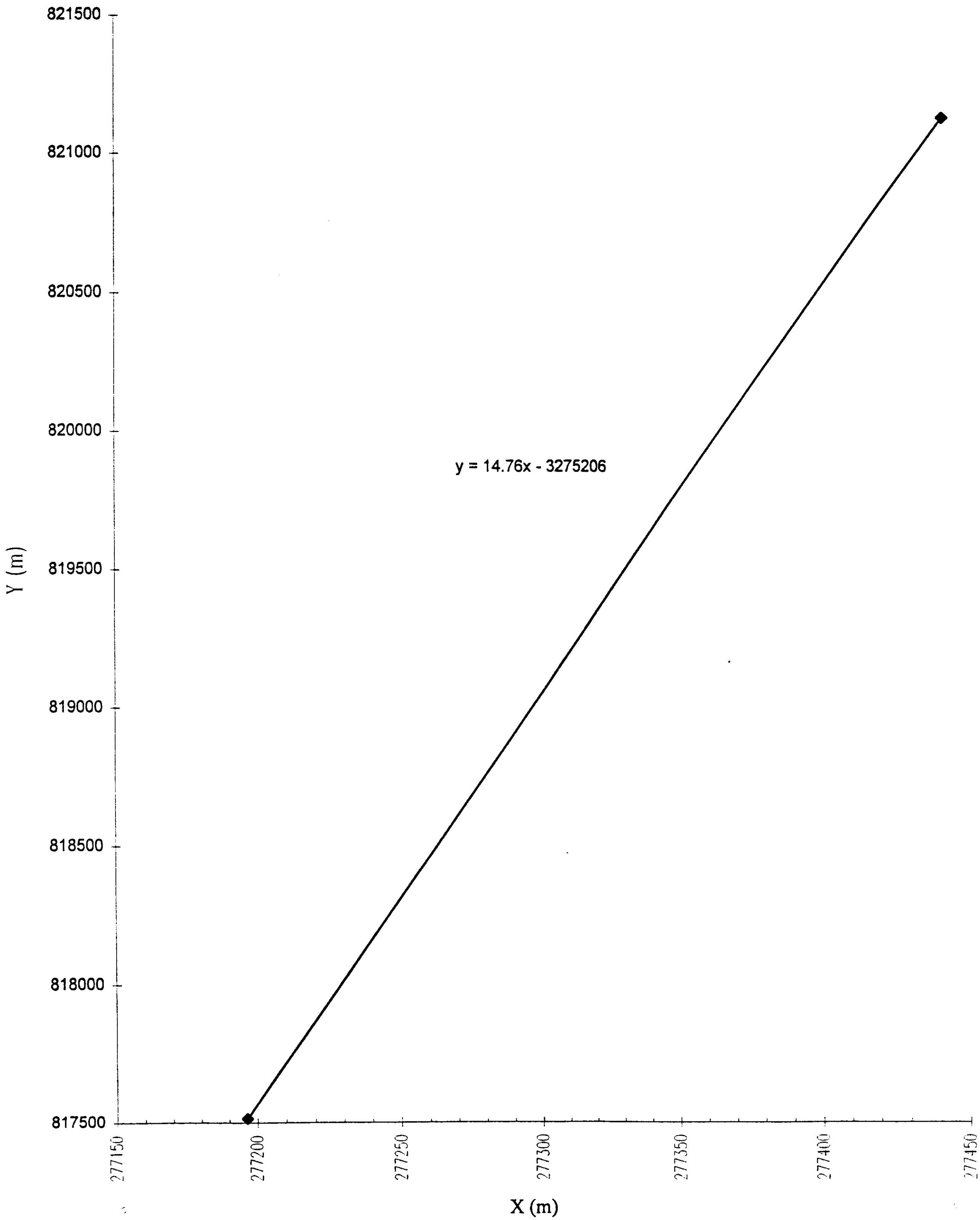

Figure C-3: Plot of hydraulic gradient for ground-water plume FS-12.

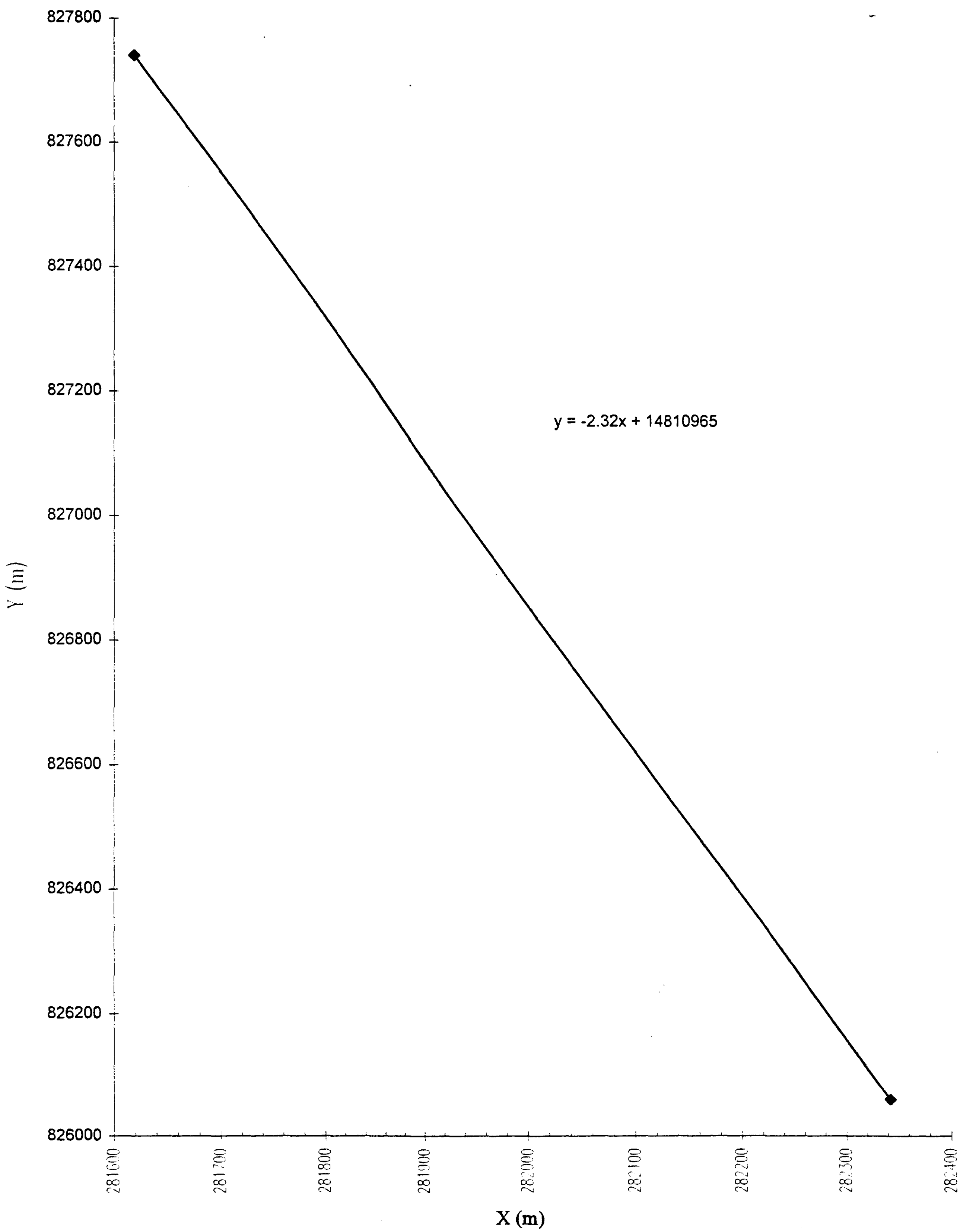

Figure C-4: Plot of hydraulic gradient for ground-water plume CS-4.

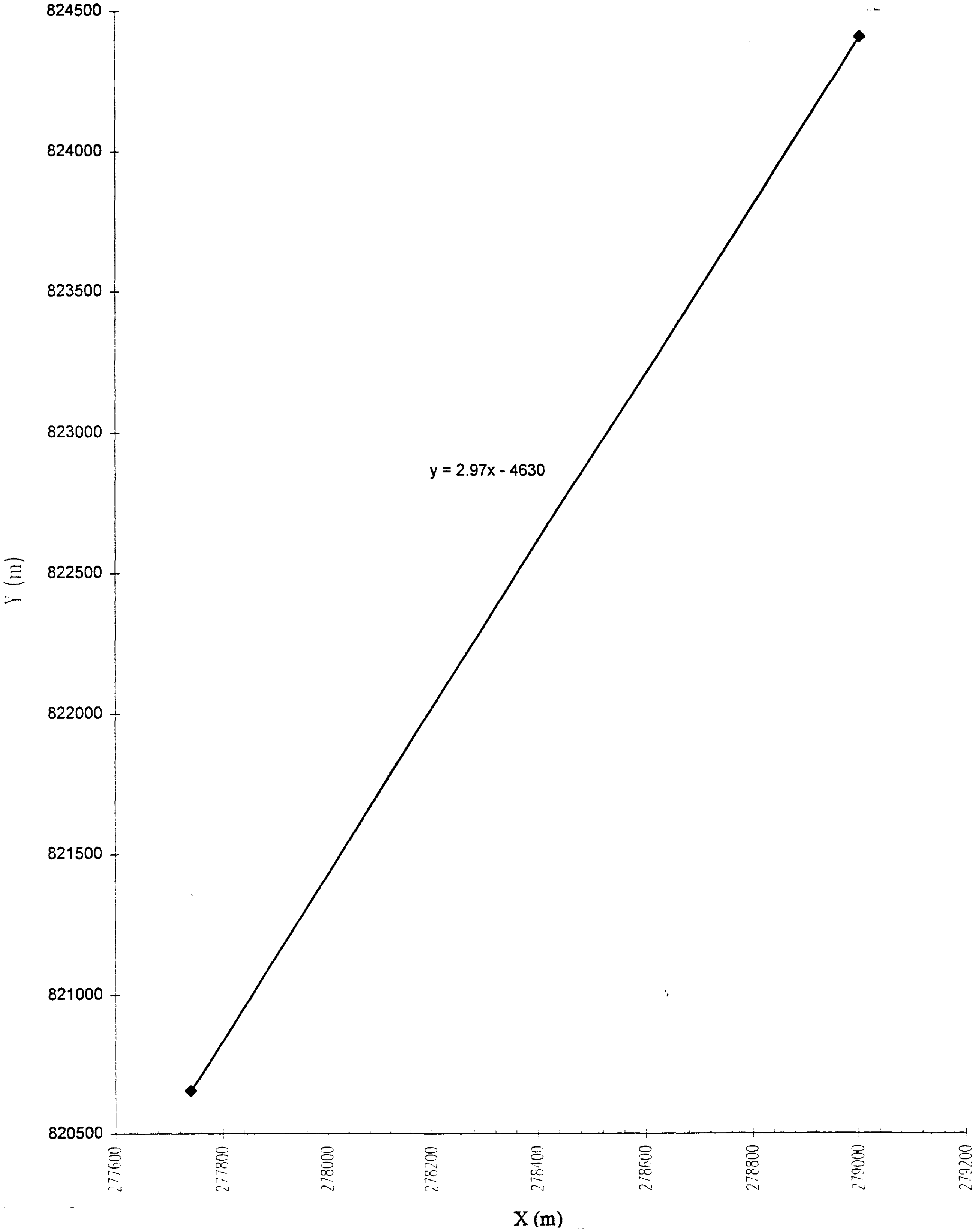

Figure C-5: Plot of hydraulic gradient for the Ashumet Valley ground-water plume.

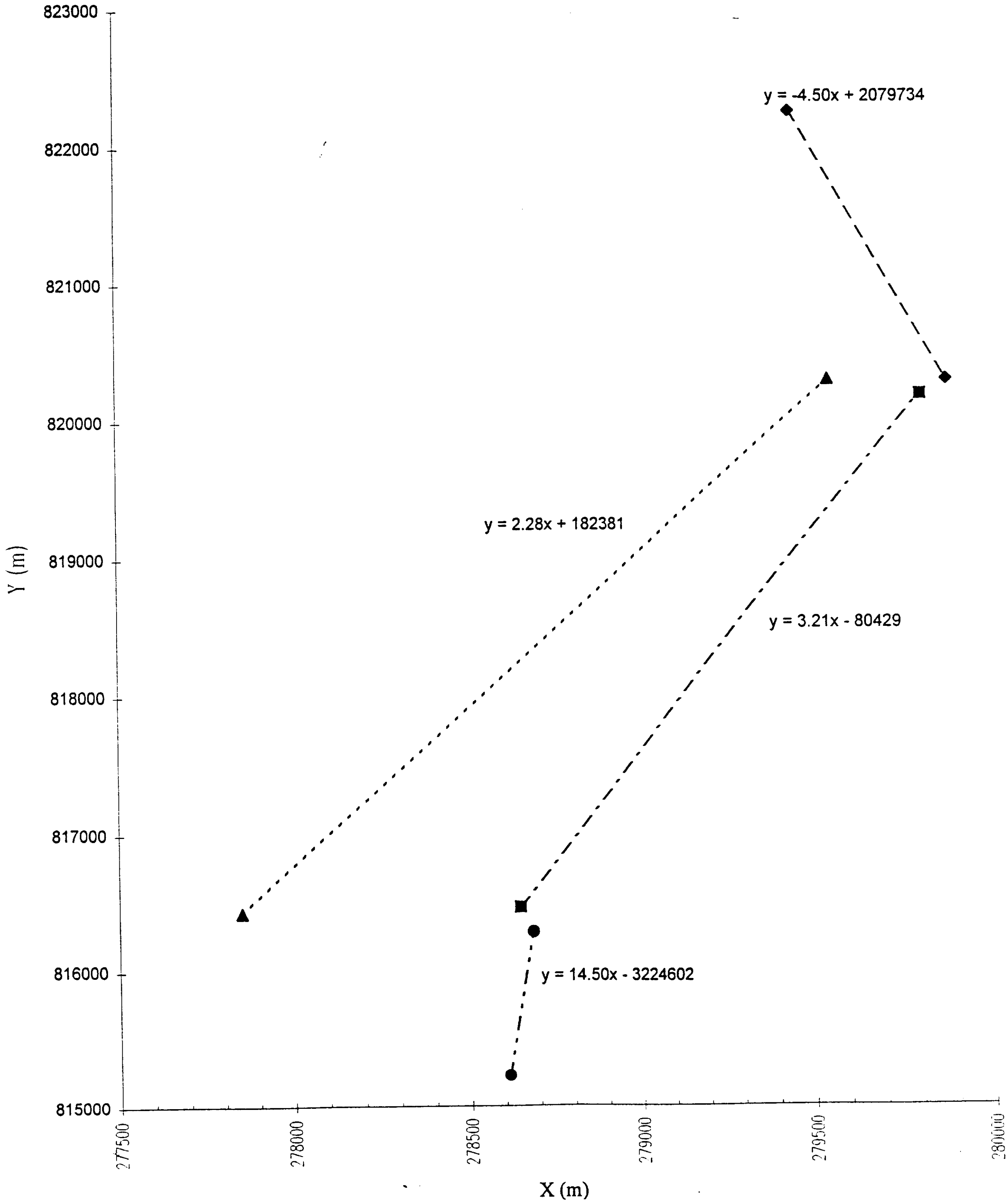

Figure C-6: Plot of hydraulic gradient for ground-water plume CS-10.

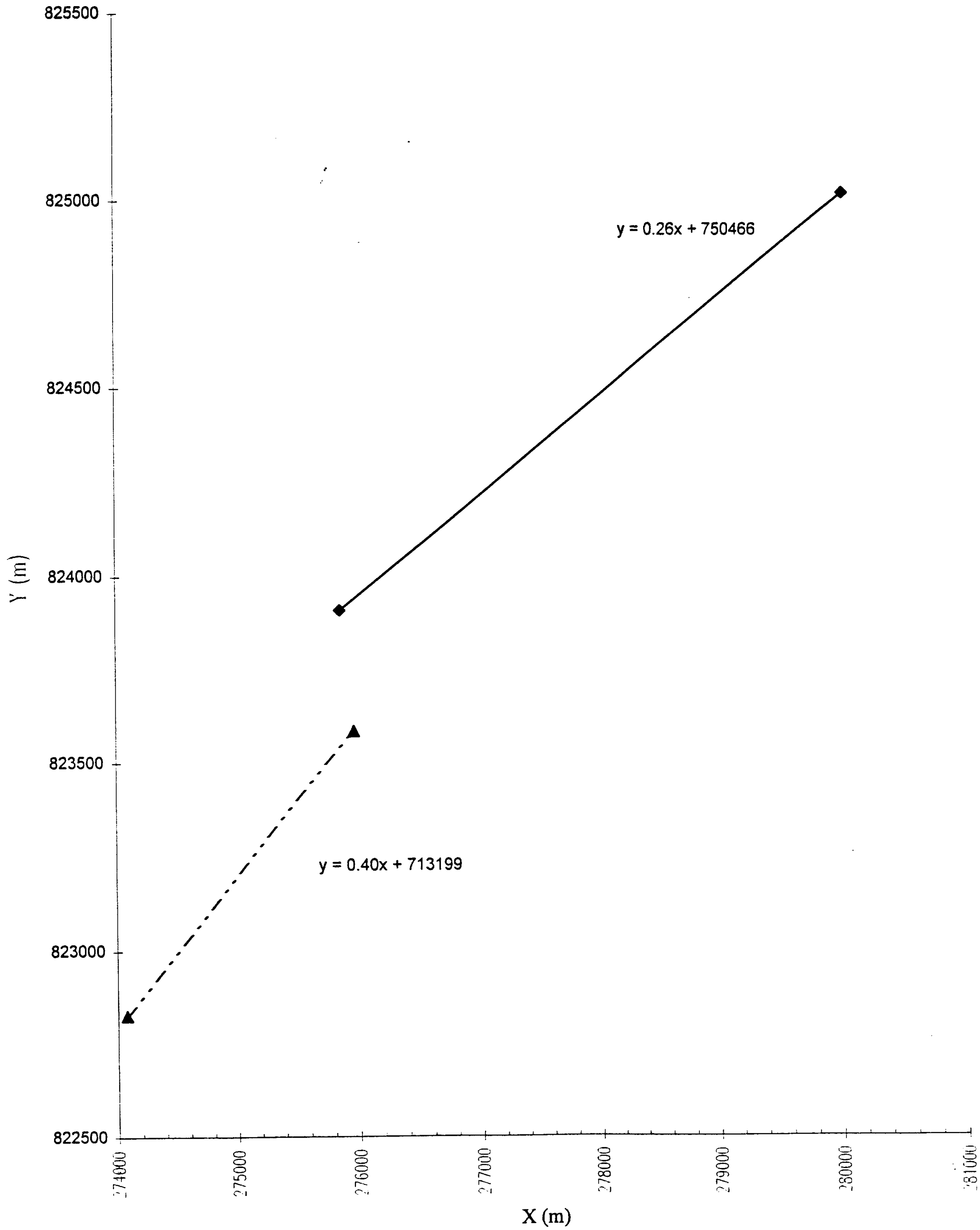

Figure C-7: Plot of hydraulic gradient for ground-water plume SD-5.

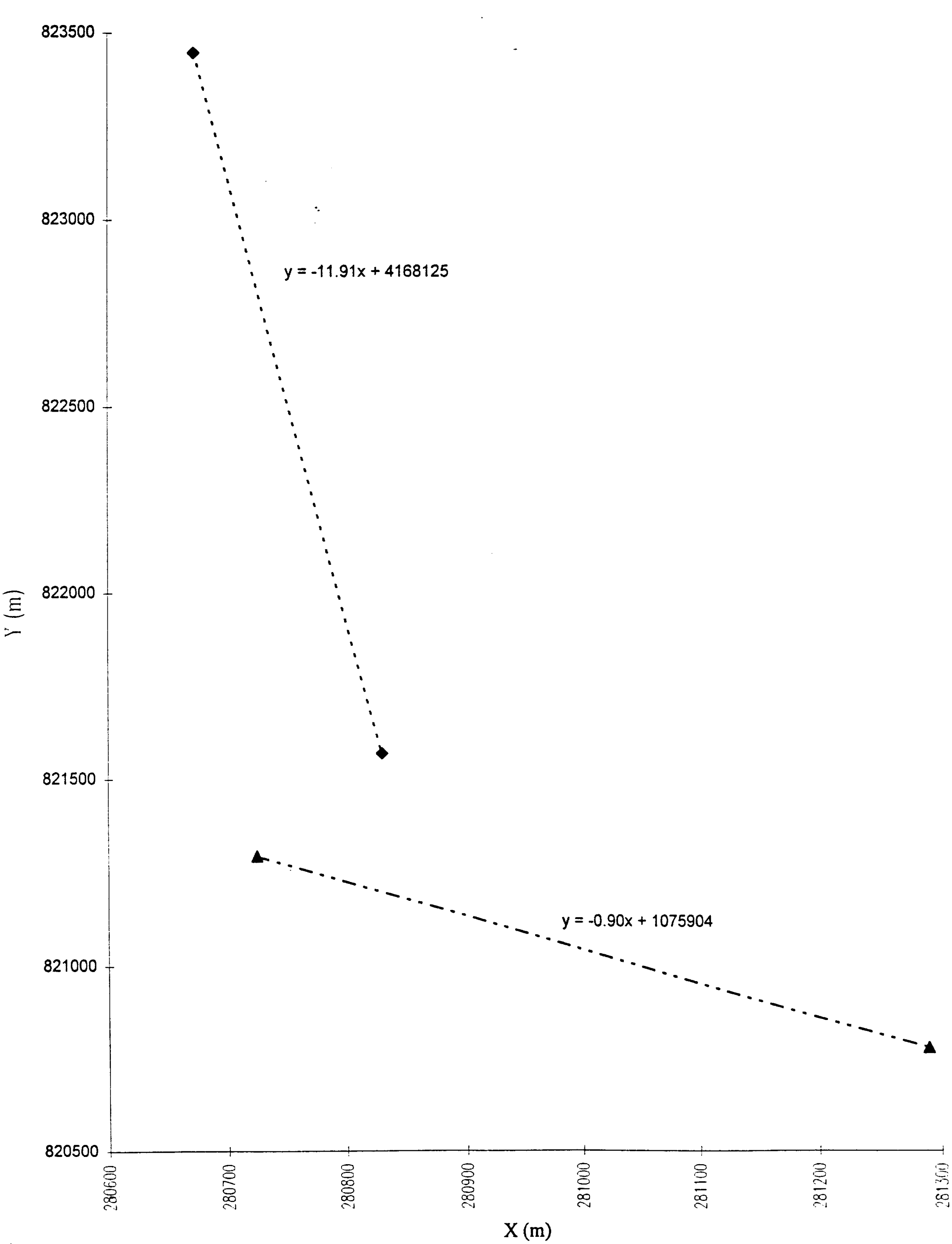

Figure C-8: Plot of hydraulic gradient for ground-water plume LF-1.